FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

ADVANCED RESEARCH PROJECTS AGENCY – ENERGY (ARPA-E)
U.S. DEPARTMENT OF ENERGY

SUPPORT GRANTS FOR PARTICIPATION IN ARPA-E GRID OPTIMIZATION (GO) COMPETITION CHALLENGE 1

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0001952
CFDA Number 81.135

Funding Opportunity Announcement (FOA) Issue Date:	Tuesday July 24, 2018
Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, Tuesday, August 28, 2018
Submission Deadline for Full Applications:	9:30 AM ET, Friday, September 7, 2018
Expected Date for Selection Notifications:	October 2018
Total Amount to Be Awarded	Approximately $5 million, subject to the availability of appropriated funds.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. ARPA-E will provide up to $250,000 per award.

- For eligibility criteria, see Section III.A of the FOA.
- To apply to this FOA, Applicants must register with and submit application materials through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). For detailed guidance on using ARPA-E eXCHANGE, see Section IV.F.1 of the FOA.
- Applicants are responsible for meeting each submission deadline. Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.
- Cost sharing is not required for this FOA.
- For detailed guidance on compliance and responsiveness criteria, see Sections III.B.1 through III.B.4 of the FOA.

Questions about this FOA? Check the Frequently Asked Questions available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, email ARPA-E-CO@hq.doe.gov (with FOA name and number in subject line); see FOA Sec. VII.A. Problems with ARPA-E eXCHANGE? Email ExchangeHelp@hq.doe.gov (with FOA name and number in subject line).

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REQUIRED DOCUMENTS CHECKLIST

For an overview of the application process, see Section IV.A of the FOA.

For guidance regarding requisite application forms, see Section IV.B of the FOA.

For guidance regarding the content and form of Full Applications see Section IV.C of the FOA.

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE
Full Application	• Each Applicant must submit a Technical Volume in Adobe PDF format by the stated deadline. Applicants may use the Technical Volume template available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/). The Technical Volume must include the following: o Executive Summary (1 page max.) o Sections 1-3 (5 pages max.) • 1. Innovation, Impact, and Proposed Work • 2. Team Organization and Capabilities • 3. Budget o Bibliographic References (no page limit) o Personal Qualification Summaries (each PQS limited to 2 pages in length, no cumulative page limit) • The Technical Volume must be accompanied by: o SF-424 (no page limit, Adobe PDF format); o SF424A (no page limit, Microsoft Excel format); and o Completed and signed Business Assurances & Disclosures Form (no page limit, Adobe PDF format).	Mandatory	IV.C	9:30 AM ET, Friday September 7, 2018

I. FUNDING OPPORTUNITY DESCRIPTION

A. AGENCY OVERVIEW

The Advanced Research Projects Agency – Energy (ARPA-E), an organization within the Department of Energy (DOE), is chartered by Congress in the America COMPETES Act of 2007 (P.L. 110-69), as amended by the America COMPETES Reauthorization Act of 2010 (P.L. 111-358) to:

"(A) to enhance the economic and energy security of the United States through the development of energy technologies that result in—
(i) reductions of imports of energy from foreign sources;
(ii) reductions of energy-related emissions, including greenhouse gases; and
(iii) improvement in the energy efficiency of all economic sectors; and
(B) to ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies."

ARPA-E issues this Funding Opportunity Announcement (FOA) under the programmatic authorizing statute codified at 42 U.S.C. § 16538. The FOA and any awards made under this FOA are subject to 2 C.F.R. Part 200 as amended by 2 C.F.R. Part 910.

ARPA-E funds research on and the development of high-potential, high-impact energy technologies that are too early for private-sector investment. The agency focuses on technologies that can be meaningfully advanced with a modest investment over a defined period of time in order to catalyze the translation from scientific discovery to early-stage technology. For the latest news and information about ARPA-E, its programs and the research projects currently supported, see: http://arpa-e.energy.gov/.

ARPA-E funds transformational research. Existing energy technologies generally progress on established "learning curves" where refinements to a technology and the economies of scale that accrue as manufacturing and distribution develop drive down the cost/performance metric in a gradual fashion. This continual improvement of a technology is important to its increased commercial deployment and is appropriately the focus of the private sector and it can be spurred by early-stage R&D supported by the applied energy offices in DOE. By contrast, ARPA-E supports high-risk, potentially transformative research that has the potential to create fundamentally new learning curves. ARPA-E R&D projects typically start with cost/performance estimates for the proposed technology that are well above the level of the competitive incumbent technology. Given the high risk inherent in these projects, many will fail to progress, but some may succeed in generating a new learning curve with a projected cost/performance metric that is significantly lower than that of the incumbent technology.

ARPA-E funds technology with the potential to be disruptive in the marketplace. The mere creation of a new learning curve does not ensure market penetration. Rather, the ultimate value of a technology is determined by the marketplace, and impactful technologies ultimately become disruptive – that is, they are widely adopted and displace existing technologies from the marketplace or create entirely new markets. ARPA-E understands that definitive proof of market disruption takes time, particularly for energy technologies. Therefore, ARPA-E funds the development of technologies that, if technically successful, have the clear disruptive potential, e.g., by demonstrating capability for manufacturing at competitive cost and deployment at scale.

ARPA-E funds applied research and development. The Office of Management and Budget defines "applied research" as an "original investigation undertaken in order to acquire new knowledge…directed primarily towards a specific practical aim or objective" and defines "development" as "creative and systematic work, drawing on knowledge gained from research and practical experience, which is directed at producing new products of processes or improving existing products or processes."[1] Applicants interested in receiving financial assistance for basic research should contact the DOE's Office of Science (http://science.energy.gov/). Office of Science national scientific user facilities (http://science.energy.gov/user-facilities/) are open to all researchers, including ARPA-E applicants and awardees. These facilities provide advanced tools of modern science including accelerators, colliders, supercomputers, light sources and neutron sources, as well as facilities for studying the nanoworld, the environment, and the atmosphere. Projects focused on early-stage R&D for the improvement of technology along defined roadmaps may be more appropriate for support through the DOE applied energy offices including: the Office of Energy Efficiency and Renewable Energy (http://www.eere.energy.gov/), the Office of Fossil Energy (http://fossil.energy.gov/), the Office of Nuclear Energy (http://www.energy.gov/ne/office-nuclear-energy), and the Office of Electricity Delivery and Energy Reliability (http://energy.gov/oe/office-electricity-delivery-and-energy-reliability).

B. PROGRAM OVERVIEW

The purpose of this FOA is to fund research and development of solution techniques that will be used by awardees to compete in Challenge 1 of the Grid Optimization (GO) Competition. The GO Competition is a series of prize challenges to accelerate the development and comprehensive evaluation of grid software solutions.[2] The first GO Competition, Challenge 1, is an algorithm competition focused on the security-constrained optimal power flow (SCOPF) problem for the electric power sector. Awardees under this FOA will be required to participate in Challenge 1. As described in detail in Appendix A1 to this FOA and on the GO Competition website (https://gocompetition.energy.gov/), Challenge 1 is anticipated to launch in the Fall of 2018. Participation in the GO Competition Challenge 1 will be open to anyone that satisfies the applicable requirements in Rules Document specified on the GO Competition website (https://gocompetition.energy.gov/competition-rules), not just those awarded under ARPA-E DE-FOA-0001952.

[1] OMB Circular A-11 (https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/assets/a11_current_year/a11_2017.pdf), Section 84, pgs. 3-4.
[2] See https://gocompetition.energy.gov/.

The purpose of this FOA is to provide grants: (i) to further incentivize and identify innovative research for solution methods applicable to Challenge 1, and (ii) to enable broader diversity in team domain expertise, i.e., to encourage teams to participate that do not traditionally focus on the particular problems that are targeted but otherwise have innovative approaches for this class of mathematical programs. While Challenge 1 focuses on a power systems problem, the Challenge and this FOA target a much broader audience (e.g., those specialized in operations research, applied mathematics, optimization methods and algorithms, controls etc.).

Existing grid software was designed for a power grid centered on conventional generation and transmission technologies. Recent years have seen major developments in new types of resources including distributed energy resources (DER), intermittent resources (wind and solar), and storage. Such emerging technologies have unique characteristics distinct from conventional resources. Emerging technologies face a prohibitive barrier within large-scale grid operations as the existing software support systems do not acknowledge these unique characteristics with the same level of accuracy and efficiency with which they capture conventional resources. As a consequence, this existing software paradigm does not allow for these assets to be used to their full potential. Furthermore, the ever-increasing emphasis on grid resilience demands innovative management of a more diverse resource portfolio, which existing grid software is not equipped to handle without overly simplifying assumptions. Simply put, in order to improve grid resiliency, the power industry must significantly advance grid software. Innovation is needed regarding the underlying simulation, optimization, and control methods in order to enable increased grid flexibility, reliability, and resilience while also substantially reducing the costs of integrating emerging technologies and resources into the electric power system.

To this end, ARPA-E has set a goal: new modern and innovative grid software to achieve a modern grid. ARPA-E is targeting key areas for innovation in grid software including, but not limited to, optimal utilization of conventional and emerging grid technologies, management of dynamic operations of the grid (including extreme event response and restoration), and management of millions of emerging distributed energy resources.

This broader effort begins with the launch of the Grid Optimization (GO) Competition. If successful, the GO Competition will accelerate the development of transformational and disruptive methods for solving problems related to the electric power grid and to provide a transparent, fair, and comprehensive evaluation of new solution methods. The GO Competition is aimed at overhauling and modernizing grid software and will be structured as multiple challenges, the first of which is expected to begin in the fall of 2018.

Each challenge in the GO Competition will culminate in a Final Event to evaluate the performance, speed, and efficiency of each Entrant's approach on standardized, realistic datasets in a controlled environment. After each final event, winners will be announced and awards provided. Entrants can enter as "Open Entrants" and can register and submit their programs (i.e., algorithmic approaches) or "Proposal Entrants" who will be provided grants under this FOA to develop their algorithmic approach for submission to Challenge 1. The GO Competition will incentivize entrepreneurial efforts that align with ARPA-E's mission to innovate in grid software. The algorithms and software solutions submitted to the GO Competition will supplement ARPA-E efforts to break down barriers to empower widespread, fast adoption of emerging grid technologies with the goal of saving billions of dollars in an energy sector with revenues reaching close to $400B per year.[3] In addition to introducing the GO Competition, this FOA provides details for potential Proposal Entrants (also referred to as "awardees" in this FOA) to apply for grants to prepare for and participate in the GO Competition Challenge 1 (see Appendix A1 for more information).

C. TECHNICAL AREAS OF FOCUS FOR APPLICANTS TO THIS FOA

For this FOA, ARPA-E seeks innovative approaches that provide fast, robust, minimal cost solution techniques for the non-convex mixed-integer optimization problem established for Challenge 1. In this FOA, ARPA-E is seeking submissions that describe novel techniques to solve this security-constrained optimal power flow problem; such a description includes, but is not limited to, alternative formulations of the problem, approximations, heuristic approaches, decomposition techniques, etc. Critical issues to discuss in the application submitted to this FOA include, but are not limited to:

- Technical details regarding the proposed approach and its applicability to large-scale, non-convex, mixed integer programs (MIP). In particular, relate the proposed effort to the problem of SCOPF and the specific formulation for Challenge 1.
- Quantitative comparisons of the proposed algorithmic approach to other state of the art SCOPF approaches and/or other generalized non-convex MIP approaches as well as provide initial evidence that the proposed approach is promising.
- Complexity of the two-stage structure (the first-stage is the pre-contingency state and the second stage is the post-contingency state) related to real power and reactive power response; approaches that ignore these complexities will be considered non-responsive (see Section III.B below for more information on ARPA-E's responsiveness review of submissions to this FOA).
- Complementarity modeling that is imposed in relation to recourse decision variables related to the real power response (i.e., participation factor driven generator response) and reactive power response (i.e., PV/PQ switching).
- Handling of the non-convexities in the network flow problem.
- Proposed approaches in terms of the GO Competition scoring criteria (https://gocompetition.energy.gov/challenges/challenge-1/scoring) and strengths and weaknesses related to finding the lowest objective function value, satisfying constraints, algorithm run-time and robustness/ability to find feasible points.
- How the proposed solution differs from state-of-the-art approaches, including citations of any pertinent literature.

[3] Energy Information Administration, "Revenue from Sales of Electricity to Ultimate Customers," https://www.eia.gov/electricity/annual/html/epa_02_03.html

In addition to the above, applicants may also:

- Provide additional evidence that their approach is fundamentally suited for future grid management challenges, not specifically included in the GO Competition Challenge 1 formulation including, but not limited to: (1) the integration of high penetrations of renewable generation and changing demand patterns, (2) the improving cost effectiveness of distributed energy resources (including storage), (3) the increasing use of power flow control and flexible Alternating Current (AC) transmission system (FACTS) devices, (4) the determination and inclusion of proxy stability constraints, (5) identification of system response to extreme events, and (6) grid restoration and resilience. These challenges introduce potentially millions more decision variables, including integer variables, added non-convexities in the network flow problem, potentially differential equations, and time-domain transient simulations of system dynamics. These challenges also bring forward the need for multi-stage stochastic programming, robust optimization, and control-theoretic approaches.
- Tailor their approach to specific “difficult” aspects of the non-convex MIP SCOPF problem. For example, one team may choose to focus efforts on efficiently considering contingencies (the two-stage structure) while another team may decide to spend their resources on dealing with the non-convex nature of the alternating current optimal power flow (ACOPF) network flow problem. Proposers should detail and justify these decisions and their tradeoffs.
- While publication of algorithmic approaches will not be required of FOA awardees (Proposal Entrants), ARPA-E encourages awardees to submit open-access journal articles or conference papers where they disseminate their approach. ARPA-E also encourages awardees to release their approach via an open-source licensing agreement. However, ARPA-E is prepared to authorize enhanced awardee intellectual property rights in the awardee’s algorithm that is submitted to the GO Competition if that will enhance the dissemination and utilization of the algorithm.

FOA Applicants should note that ARPA-E is open to exact solution methods, approximations, or heuristics as long as they are targeted at the prior core concerns. Applicants should describe their approach for both the mathematical problem presented in Appendix A2 and the complete formulation presented on the GO Competition Challenge 1 website (https://gocompetition.energy.gov/challenges/challenge-1/formulation). Applicants should also consult (https://gocompetition.energy.gov/challenges/challenge-1/scoring), which describes the scoring mechanisms that will be used to choose the GO Competition Challenge 1 winners.

D. POST AWARD – PARTICIPATION IN THE GO COMPETITION CHALLENGE 1

Awardees[4] under this FOA will be required to compete in the GO Competition Challenge 1. Awardees under this FOA must also complete the following in addition to those requirements applicable to all GO Competition Challenge 1 Entrants:

- **Task 1:** Register for the GO Competition on the competition website (https://gocompetition.energy.gov/); awardees under this FOA may not participate anonymously.
- **Task 2:** Test their software approach at least once by month 3 of the GO Competition (by using the GO Competition software platform); their results must be displayed on the leaderboards.
- **Task 3:** Participate in the Trial 1 event at month 6; their results must be displayed on the leaderboards.
- **Task 4:** Participate in the Trial 2 event at month 9; their results must be displayed on the leaderboards.
- **Task 5:** Participate in the Challenge 1 Final Event; their results must be displayed on the leaderboards.

Challenge 1 prize winners will receive their $100,000 prize purse as additional grant funding from ARPA-E to further develop their algorithm. Receipt of this funding: (i) requires submission of a brief application, (ii) is subject to ARPA-E's standard grant terms and conditions (including cost sharing requirements, if any), and (iii) is contingent upon the successful conclusion of award negotiations. ARPA-E reserves the right to discontinue negotiations without the award of a grant in the event the parties cannot agree on the terms of the prospective grant.

[4] Awardees are the applicants to this FOA that are selected for and ultimately receive a grant after successfully completing award negotiations.

II. Award Information

A. Award Overview

ARPA-E expects to make $5 million available for new awards under this FOA, subject to the availability of appropriated funds. ARPA-E will provide up to $250,000 per award.

B. ARPA-E Funding Agreements

1. Grants

ARPA-E anticipates awarding fixed-amount grants, except as set forth in the following sub-section, resulting from this FOA. ARPA-E will only award a fixed-amount grant in instances where it can be assured that the prospective awardee will not realize any increment above the actual cost of performing work. Five equal payments will be made, one each upon completion of the tasks listed in Section I.D. Payment following Task 5 also requires certification to ARPA-E that all project activity has been completed. For additional information about fixed-amount awards refer to 2 C.F.R. § 200.45 and 2 C.F.R. § 200.201.

In addition to the aforementioned certification, awardees will be required, *inter alia*, to submit a final technical report to ARPA-E and to obtain prior approval of the ARPA-E Contracting Officer for changes in principal investigator, project partner, or scope of project effort.

2. Funding Agreements with FFRDCs/DOE Labs, GOGOs, and Federal Instrumentalities

Any Federally Funded Research and Development Centers (FFRDC) involved as a member of an Awardee Team must provide the information requested in the "FFRDC Lab Authorization" and "Field Work Proposal" section of the Business Assurances & Disclosures Form, which is submitted with the Applicant's Full Application.

When a FFRDC/DOE Lab (including the National Energy Technology Laboratory or NETL) is the *lead organization* for an Awardee Team, ARPA-E executes a funding agreement directly with the FFRDC/DOE Lab and a single, separate Grant with the rest of the Awardee Team. Notwithstanding the use of multiple agreements, the FFRDC/DOE Lab is the lead organization for the entire project, including all work performed by the FFRDC/DOE Lab and the rest of the Awardee Team.

When a FFRDC/DOE Lab is a *member* of an Awardee Team, ARPA-E executes a funding agreement directly with the FFRDC/DOE Lab and a single, separate Grant with the rest of the

Awardee Team. Notwithstanding the use of multiple agreements, the Prime Recipient under the Grant is the lead organization for the entire project, including all work performed by the FFRDC/DOE Lab and the rest of the Awardee Team.

Funding agreements with DOE/NNSA FFRDCs take the form of Work Authorizations issued to DOE/NNSA FFRDCs through the DOE/NNSA Field Work Proposal system for work performed under Department of Energy Management & Operation Contracts. Funding agreements with non-DOE/NNSA FFRDCs, GOGOs (including NETL), and Federal instrumentalities (e.g., Tennessee Valley Authority) will be consistent with the sponsoring agreement between the U.S. Government and the Laboratory. Any funding agreement with a FFRDC or GOGO will have similar terms and conditions as ARPA-E's Model Grant (https://arpa-e.energy.gov/?q=site-page/funding-agreements).

Non-DOE GOGOs and Federal agencies may be proposed to provide support to the Awardee Team members on an applicant's project, through a Cooperative Research and Development Agreement (CRADA) or similar agreement.

III. Eligibility Information

A. Eligible Applicants

This FOA is open to U.S. universities, national laboratories, industry, and individuals. General eligibility requirements are below. In addition, the following **are not eligible for funding under this FOA**:

- Federal employees;
- ARPA-E support contractors, their employees and their spouses, dependents, and other household members;
- Any individual funded by ARPA-E to support or facilitate the design and development of Challenge 1 or to create or validate datasets to be used in Challenge 1 of the GO Competition;[5,6]
- Any individual, along with their spouses, dependents, and household members, working for/supporting the GO Competition Administrator;[7]
- Any DOE Federal employee, prior ARPA-E employee, or support contractor, along with their spouses, dependents, and household members, that assisted, are assisting, or will assist in the design or operation of Challenge 1 of the GO Competition, in creation of the GO Competition software platform for Challenge 1, or in the evaluation of the Entrant submitted approaches for Challenge 1;[8]
- Any individual or organization that is on the Specially Designated Nationals list.[9]

1. Individuals

U.S. citizens or permanent residents may apply for funding in their individual capacity as a Standalone Applicant,[10] as the lead for an Applicant Team,[11] or as a member of an Applicant

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[5] This group includes, but is not limited to, individuals working on behalf of ARPA-E through contracts at the National Renewable Energy Laboratory, the Pacific Northwest National Laboratory, Texas A&M University, and the University of Wisconsin and includes any individual that has worked on the .

[6] If such individuals wish to test their algorithmic approaches on the GO Competition Challenge 1 platform, they may do so only after the GO Competition Challenge 1 has ended and all publicly available datasets have been released to the public. These individuals cannot submit their algorithmic approach at any time before the end of the GO Competition Challenge 1.

[7] The Pacific Northwest National Laboratory (PNNL) is acting as the GO Competition Administrator, the host team of the competition. Additionally, there are sub-contractors that are supporting PNNL and ARPA-E in regards to the GO Competition Challenge 1 (Arizona State University, National Renewable Energy Laboratory, Texas A&M University, the University of Wisconsin-Madison).

[8] This group includes, but is not limited to, specific individuals working on behalf of ARPA-E through contracts at Arizona State University, the Pacific Northwest National Laboratory, the University of Wisconsin, and Quantitative Scientific Solutions.

[9] https://www.treasury.gov/resource-center/sanctions/SDN-List/Pages/default.aspx

[10] A Standalone Applicant is an Applicant that applies for funding on its own, not as part of a Applicant Team.

[11] The term "Applicant Team" is used to mean any entity with multiple players working collaboratively and could encompass anything from an existing organization to an ad hoc teaming arrangement. An Applicant Team consists of the Prime Recipient, Subrecipients, and others performing or otherwise supporting work under an ARPA-E funding agreement.

Team. However, for those applying in their personal capacity: ARPA-E will only award funding to a U.S. incorporated entity, which may be formed by the selected individual Applicant.

2. Domestic Entities

For-profit entities, educational institutions, and nonprofits[12] that are incorporated in the United States, including U.S. territories, are eligible to apply for funding as a Standalone Applicant, as the lead organization for an Applicant Team, or as a member of an Applicant Team.

FFRDCs/DOE Labs are eligible to apply for funding as the lead organization for an Applicant Team or as a member of an Applicant Team that includes institutions of higher education, companies, research foundations, or trade and industry research collaborations, but not as a Standalone Applicant.

State, local, and tribal government entities are eligible to apply for funding as a member of an Applicant Team, but not as a Standalone Applicant or as the lead organization for an Applicant Team.

Federal agencies and instrumentalities (other than DOE) are eligible to apply for funding as a member of an Applicant Team, but not as a Standalone Applicant or as the lead organization for an Applicant Team.

3. Foreign Entities

U.S. incorporated subsidiaries of foreign entities, whether for-profit or otherwise, are eligible to apply for funding under this FOA as a Standalone Applicant, as the lead organization for an Applicant Team, or as a member of an Applicant Team, subject to the requirements in 2 C.F.R. 910.124, which includes requirements that the entity's participation in this FOA's Program be in the economic interest of the U.S. The Full Application must state the nature of the corporate relationship between the foreign entity and domestic subsidiary or affiliate.

Entities not incorporated in the U.S., whether for-profit or otherwise, are not eligible to apply for funding, but may be proposed by an Applicant as a member of an Applicant Team.

All work under an ARPA-E award must be performed in the U.S. The Applicants may request a waiver of this requirement in the Business Assurances & Disclosures Form, which is submitted with the Full Application and can be found at https://arpa-e-foa.energy.gov/. Please refer to the Business Assurances & Disclosures Form for guidance on the content and form of the request.

12 Nonprofit organizations described in section 501(c)(4) of the Internal Revenue Code of 1986 that engaged in lobbying activities after December 31, 1995 are not eligible to apply for funding as a Prime Recipient or Subrecipient.

4. CONSORTIUM ENTITIES

Consortia, which may include domestic and foreign entities, must designate one member of the consortium as the consortium representative to the Applicant Team. The consortium representative must be incorporated in the United States. The eligibility of the consortium will be determined by reference to the eligibility of the consortium representative under Section III.A of the FOA. Each consortium must have an internal governance structure and a written set of internal rules. Upon request, the consortium entity must provide a written description of its internal governance structure and its internal rules to the Contracting Officer (ARPA-E-CO@hq.doe.gov).

Unincorporated consortia must provide the Contracting Officer with a collaboration agreement, commonly referred to as the articles of collaboration, which sets out the rights and responsibilities of each consortium member. This collaboration agreement binds the individual consortium members together and shall include the consortium's:

- Management structure;
- Method of making payments to consortium members;
- Means of ensuring and overseeing members' efforts on the project;
- Provisions for members' cost sharing contributions; and
- Provisions for ownership and rights in intellectual property developed previously or under the agreement.

B. COST SHARING

Cost Sharing is not required for this FOA.

C. OTHER

1. COMPLIANT CRITERIA

Full Applications are deemed compliant if:

- The Applicant meets the eligibility requirements in Section III.A of the FOA;
- The Full Application complies with the content and form requirements in Section IV.C of the FOA; and

- The Applicant entered all required information, successfully uploaded all required documents, and clicked the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA.

Full Applications found to be noncompliant may not be merit reviewed or considered for award. ARPA-E may not review or consider noncompliant Full Applications, including Full Applications submitted through other means, Full Applications submitted after the applicable deadline, and incomplete Full Applications. A Full Application is incomplete if it does not include required information and documents, such as Forms SF-424 and SF-424A. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.

2. RESPONSIVENESS CRITERIA

ARPA-E performs a preliminary technical review of Full Applications.
The following types of submissions may be deemed nonresponsive and may not be reviewed or considered:

- Submissions that fall outside the technical parameters specified in this FOA.
- Submissions that have been submitted in response to other currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from applications submitted in response to other currently issued ARPA-E FOAs.
- Submissions for basic research aimed solely at discovery and/or fundamental knowledge generation.
- Submissions for large-scale demonstration projects of existing technologies.
- Submissions for proposed technologies that represent incremental improvements to existing technologies.
- Submissions for proposed technologies that are not based on sound scientific principles (e.g., violates a law of thermodynamics).
- Submissions for proposed technologies that are not transformational, as described in Section I.A of the FOA.
- Submissions for proposed technologies that do not have the potential to become disruptive in nature, as described in Section I.A of the FOA. Technologies must be scalable such that they could be disruptive with sufficient technical progress.
- Submissions that are not distinct in scientific approach or objective from activities currently supported by or actively under consideration for funding by any other office within Department of Energy.
- Submissions that are not distinct in scientific approach or objective from activities currently supported by or actively under consideration for funding by other government agencies or the private sector.

- Submissions that describe a technology but do not propose a R&D plan that allows ARPA-E to evaluate the submission under the applicable merit review criteria provided in Section V.A of the FOA.

3. Submissions Specifically not of Interest

Submissions that propose the following will be deemed nonresponsive and will not be merit reviewed or considered:

- Approaches that do not address the structure of the two-stage scenario-based mathematical program are not of interest (i.e., there is a first-stage, a pre-contingency base-case state, and there is a second-stage, a post-contingency state; these second-stage constraints are referred to as security constraints or the security criteria).
- Approaches that completely ignore the non-convexities in this network flow problem (i.e., approaches that ignore voltage, reactive power, and other aspects within ACOPF problems that cause non-convexities).

4. Limitation on Number of Submissions

ARPA-E is not limiting the number of submissions from Applicants. Applicants may submit more than one application to this FOA, provided that each application is scientifically distinct.

As established by the Rules document for the GO Competition Challenge 1, https://gocompetition.energy.gov/competition-rules, individuals cannot be members of multiple Entrant Teams. A person can be on no more than one Entrant Team (Proposal Entrant Team or Open Entrant Team; see the Rules document in https://gocompetition.energy.gov/competition-rules for more information). If an individual person is listed on multiple applications to this FOA, ARPA-E will select **no more than** one of those applications for award negotiations.

IV. APPLICATION AND SUBMISSION INFORMATION

A. APPLICATION PROCESS OVERVIEW

1. REGISTRATION IN ARPA-E eXCHANGE

The first step in applying to this FOA is registration in ARPA-E eXCHANGE, ARPA-E's online application portal. For detailed guidance on using ARPA-E eXCHANGE, please refer to Section IV.F.1 of the FOA and the "ARPA-E eXCHANGE Applicant Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

2. FULL APPLICATIONS

Applicants must submit a Full Application by the deadline stated in the FOA. Section IV.C of the FOA provides instructions on submitting a Full Application.

ARPA-E performs a preliminary review of Full Applications to determine whether they are compliant and responsive, as described in Section III.B of the FOA. Full Applications found to be noncompliant or nonresponsive may not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A.1 and V.B.1 of the FOA.

3. PRE-SELECTION CLARIFICATIONS AND "DOWN-SELECT" PROCESS

Once ARPA-E completes its review of Full Applications, it may, at the Contracting Officer's discretion, conduct a pre-selection clarification process and/or perform a "down-select" of Full Applications. Through the pre-selection clarification process or down-select process, ARPA-E may obtain additional information from select Applicants through pre-selection meetings, webinars, videoconferences, conference calls, written correspondence, or site visits that can be used to make a final selection determination. ARPA-E will not reimburse Applicants for travel and other expenses relating to pre-selection meetings or site visits, nor will these costs be eligible for reimbursement as pre-award costs.

ARPA-E may select applications for award negotiations and make awards without pre-selection meetings and site visits. Participation in a pre-selection meeting or site visit with ARPA-E does not signify that Applicants have been selected for award negotiations.

4. SELECTION FOR AWARD NEGOTIATIONS

ARPA-E carefully considers all of the information obtained through the application process and makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A.1 and V.B.1 of the FOA. The Selection

Official may select all or part of a Full Application for award negotiations. The Selection Official may also postpone a final selection determination on one or more Full Applications until a later date, subject to availability of funds and other factors. ARPA-E will enter into award negotiations only with selected Applicants.

Applicants are promptly notified of ARPA-E's selection determination. ARPA-E may stagger its selection determinations. As a result, some Applicants may receive their notification letter in advance of other Applicants. Please refer to Section VI.A of the FOA for guidance on award notifications.

B. Application Forms

Required forms for Full Applications are available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov), including the SF-424 and SF-424A. Applicants may use the templates available on ARPA-E eXCHANGE, including the template for the Technical Volume of the Full Application and the template for the Business Assurances & Disclosures Form. A sample response to the Business Assurances & Disclosures Form is available on ARPA-E eXCHANGE.

C. Content and Form of Full Applications

Full Applications must conform to the following formatting requirements:

- Each document must be submitted in the file format prescribed below.
- The Full Application must be written in English.
- All pages must be formatted to fit on 8-1/2 by 11 inch paper with margins not less than one inch on every side. Single space all text and use Times New Roman typeface, a black font color, and a font size of 12 point or larger (except in figures and tables).
- The ARPA-E assigned Control Number, the Lead Organization Name, and the Principal Investigator's Last Name must be prominently displayed on the upper right corner of the header of every page. Page numbers must be included in the footer of every page.

Full Applications found to be noncompliant or nonresponsive may not be merit reviewed or considered for award (see Section III.B of the FOA).

Each Full Application should be limited to a single concept or technology. Unrelated concepts and technologies should not be consolidated in a single Full Application.

Fillable Full Application template documents are available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov/.

Full Applications must conform to the content requirements described below.

Component	Required Format	Description and Information
Technical Volume	PDF	The centerpiece of the Full Application. Provides a detailed description of the proposed R&D project and Applicant Team. A Technical Volume template is available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/).
SF-424	PDF	Application for Federal Assistance (https://arpa-e-foa.energy.gov/). Applicants are responsible for ensuring that the proposed amounts listed in eXCHANGE match those listed on forms SF-424 and SF-424A. Inconsistent submissions may impact ARPA-E's final award determination.
SF-424A	XLS	Budget Information – Non-Construction Programs (https://arpa-e-foa.energy.gov/)
Business Assurances & Disclosures Form	PDF	Requires the Applicant to make responsibility disclosures and disclose potential conflicts of interest within the Applicant Team. Requires the Applicant to disclose applications for funding currently pending with Federal and non-Federal entities, and disclose funding from Federal and non-Federal entities for work in the same technology area as the proposed R&D project. If the Applicant is a FFRDC/DOE Lab, requires the Applicant to provide written authorization from the cognizant Federal agency and, if a DOE/NNSA FFRDC/DOE Lab, a Field Work Proposal. Allows the Applicant to request a waiver or modification of the Performance of Work in the United States requirement. This form is available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov/. A sample response to the Business Assurances & Disclosures Form is also available on ARPA-E eXCHANGE.

ARPA-E provides detailed guidance on the content and form of each component below.

1. First Component: Technical Volume

The Technical Volume must be submitted in Adobe PDF format. A Technical Volume template is available at https://arpa-e-foa.energy.gov/. The Technical Volume must conform to the content and form requirements included within the template, including maximum page lengths. If Applicants exceed the maximum page lengths specified for each section, ARPA-E will review only the authorized number of pages and disregard any additional pages.

Applicants must provide sufficient citations and references to the primary research literature to justify the claims and approaches made in the Technical Volume. ARPA-E and reviewers may review primary research literature in order to evaluate applications. <u>However, ARPA-E and reviewers are under no obligation to review cited sources</u>.

2. SECOND COMPONENT: SF-424

The SF-424 must be submitted in Adobe PDF format. This form is available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov/.

The SF-424 includes instructions for completing the form. Applicants are required to complete all required fields in accordance with the instructions.

Prime Recipients and Subrecipients are required to complete SF-LLL (Disclosure of Lobbying Activities), available at https://www.grants.gov/forms/post-award-reporting-forms.html, if any non-Federal funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any Federal agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with your application or funding agreement. The completed SF-LLL must be appended to the SF-424.

ARPA-E provides the following supplemental guidance on completing the SF-424:

- Each Applicant Team should submit only one SF-424 (i.e., a Subrecipient should not submit a separate SF-424).
- The list of certifications and assurances in Block 21 can be found at http://energy.gov/management/downloads/certifications-and-assurances-use-sf-424.
- The dates and dollar amounts on the SF-424 are for the entire period of performance (from the project start date to the project end date), not a portion thereof.
- Applicants are responsible for ensuring that the proposed costs listed in eXCHANGE match those listed on forms SF-424 and SF-424A. Inconsistent submissions may impact ARPA-E's final award determination.

3. THIRD COMPONENT: SF-424A

Applicants are required to complete the SF-424A Excel spreadsheet. This form is available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov/.

4. FOURTH COMPONENT: BUSINESS ASSURANCES & DISCLOSURES FORM

Applicants are required to provide the information requested in the Business Assurances & Disclosures Form. The information must be submitted in Adobe PDF format. A fillable Business

Assurances & Disclosures Form template is available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov/. A sample response to the Business Assurances & Disclosures Form is also available on ARPA-E eXCHANGE.

As described in the Business Assurances & Disclosures Form, the Applicant is required to:

- Disclose conditions bearing on responsibility, such as criminal convictions and Federal tax liability;
- Disclose potential conflicts of interest within the Applicant Team;
- If the Applicant is a FFRDC/DOE Lab, submit written authorization from the cognizant Federal agency; and
- If the Applicant is a DOE/NNSA FFRDC/DOE Lab, submit a Field Work Proposal.

In addition, ARPA-E is required by statute to "accelerat[e] transformational technological advances in areas that industry is by itself not likely to undertake because of technical and financial uncertainty."[13] In accordance with ARPA-E's statutory mandate, the Applicant is required to:

- Disclose any applications for the same project or related work currently pending with any Federal or non-Federal entities; and
- Disclose all current funding for work in the same technology area as the proposed project received from any Federal or non-Federal entity.

Finally, the Applicant may use the Business Assurances & Disclosures Form to request authorization to perform some work overseas.

D. Intergovernmental Review

This program is not subject to Executive Order 12372 (Intergovernmental Review of Federal Programs).

[13] America COMPETES Act, Pub. L. No. 110-69, § 5012 (2007), as amended (codified at 42 U.S.C. § 16538).

E. Award Limitations

1. Foreign Travel

ARPA-E generally does not fund projects that involve foreign travel. Recipients are required to obtain written authorization from the Contracting Officer before traveling abroad.

2. Performance of Work in the United States

ARPA-E strongly encourages interdisciplinary and cross-sectoral collaboration spanning organizational boundaries. Such collaboration enables the achievement of scientific and technological outcomes that were previously viewed as extremely difficult, if not impossible.

ARPA-E requires all work under ARPA-E funding agreements to be performed in the United States – i.e., Prime Recipients must perform all work in the United States. However, Applicants may request a waiver of this requirement where their project would materially benefit from, or otherwise requires, certain work to be performed overseas.

Applicants seeking a waiver of this requirement are required to include an explicit request in the Business Assurances & Disclosures Form, which is part of the Full Application submitted to ARPA-E. Such waivers are granted where there is a demonstrated need, as determined by ARPA-E.

3. Lobbying

Prime Recipients and Subrecipients may not use any Federal funds, directly or indirectly, to influence or attempt to influence, directly or indirectly, congressional action on any legislative or appropriation matters pending before Congress, other than to communicate to Members of Congress as described in 18 U.S.C. § 1913. This restriction is in addition to those prescribed elsewhere in statute and regulation.

Prime Recipients and Subrecipients are required to complete and submit SF-LLL, "Disclosure of Lobbying Activities" (https://www.grants.gov/forms/post-award-reporting-forms.html) if any non-Federal funds have been paid or will be paid to any person for influencing or attempting to influence any of the following in connection with your application:

- An officer or employee of any Federal agency,
- A Member of Congress,
- An officer or employee of Congress, or

- An employee of a Member of Congress.

4. Conference Spending

Prime Recipients and Subrecipients may not use any Federal funds to:

- Defray the cost to the United States Government of a conference held by any Executive branch department, agency, board, commission, or office which is not directly and programmatically related to the purpose for which their ARPA-E award is made and for which the cost to the United States Government is more than $20,000; or

- To circumvent the required notification by the head of any such Executive Branch department, agency, board, commission, or office to the Inspector General (or senior ethics official for any entity without an Inspector General), of the date, location, and number of employees attending such a conference.

5. Independent Research and Development

ARPA-E does not fund Independent Research and Development (IR&D) as part of an indirect cost rate under its financial assistance awards. IR&D, as defined at FAR 31.205-18(a), includes cost of effort that is not sponsored by an assistance agreement or required in performance of a contract, and that consists of projects falling within the four following areas: (i) basic research, (ii) applied research, (iii) development, and (iv) systems and other concept formulation studies.

ARPA-E's goals are to enhance the economic and energy security of the United States through the development of energy technologies and ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies. ARPA-E accomplishes these goals by providing financial assistance for energy technology projects, and has well recognized and established procedures for supporting research through competitive financial assistance awards based on merit review of proposed projects. Reimbursement for independent research and development costs through the indirect cost mechanism could circumvent this competitive process.

To ensure that all projects receive similar and equal consideration, eligible organizations may compete for direct funding of independent research projects they consider worthy of support by submitting proposals for those projects to ARPA-E. Since proposals for these projects may be submitted for direct funding, costs for independent research and development projects are not allowable as indirect costs under ARPA-E awards. IR&D costs, however, would still be included in the direct cost base that is used to calculate the indirect rate so as to ensure an appropriate allocation of indirect costs to the organization's direct cost centers.

F. OTHER SUBMISSION REQUIREMENTS

1. USE OF ARPA-E eXCHANGE

To apply to this FOA, Applicants must register with ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). Full Applications must be submitted through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/login.aspx). ARPA-E will not review or consider applications submitted through other means (e.g., fax, hand delivery, email, postal mail). For detailed guidance on using ARPA-E eXCHANGE, please refer to the "ARPA-E eXCHANGE Applicant Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

Upon creating an application submission in ARPA-E eXCHANGE, Applicants will be assigned a Control Number. If the Applicant creates more than one application submission, a different Control Number will be assigned for each application.

Once logged in to ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/login.aspx), Applicants may access their submissions by clicking the "My Submissions" link in the navigation on the left side of the page. Every application that the Applicant has submitted to ARPA-E and the corresponding Control Number is displayed on that page. If the Applicant submits more than one application to a particular FOA, a different Control Number is shown for each application.

Applicants are responsible for meeting each submission deadline in ARPA-E eXCHANGE. **Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.** Under normal conditions (i.e., at least 48 hours in advance of the submission deadline), Applicants should allow at least 1 hour to submit a Full Application. In addition, Applicants should allow at least 15 minutes to submit a Reply to Reviewer Comments. Once the application is submitted in ARPA-E eXCHANGE, Applicants may revise or update their application until the expiration of the applicable deadline.

Applicants should not wait until the last minute to begin the submission process. During the final hours before the submission deadline, Applicants may experience server/connection congestion that prevents them from completing the necessary steps in ARPA-E eXCHANGE to submit their applications. **ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.**

ARPA-E may not review or consider incomplete applications and applications received after the deadline stated in the FOA. Such applications may be deemed noncompliant (see Section III.B.1 of the FOA). The following errors could cause an application to be deemed "incomplete" and thus noncompliant:

- Failing to comply with the form and content requirements in Section IV of the FOA;
- Failing to enter required information in ARPA-E eXCHANGE;

- Failing to upload required document(s) to ARPA-E eXCHANGE;
- Failing to click the “Submit” button in ARPA-E eXCHANGE by the deadline stated in the FOA;
- Uploading the wrong document(s) or application(s) to ARPA-E eXCHANGE; and
- Uploading the same document twice, but labeling it as different documents. (In the latter scenario, the Applicant failed to submit a required document.)

ARPA-E urges Applicants to carefully review their applications and to allow sufficient time for the submission of required information and documents.

V. APPLICATION REVIEW INFORMATION

A. CRITERIA

ARPA-E performs a preliminary review of Full Applications to determine whether they are compliant and responsive (see Section III.B of the FOA).

ARPA-E considers a mix of quantitative and qualitative criteria in determining whether to select a Full Application for award negotiations.

1. CRITERIA FOR FULL APPLICATIONS

Full Applications are evaluated based on the following criteria:

(1) *Impact of the Proposed Technology* (35%) - This criterion involves consideration of the following:

- Thorough understanding of the current state-of-the-art and presentation of an innovative technical approach to significantly improve performance over the current state-of-the-art;
- Awareness of competing commercial and emerging technologies and identification of how the proposed concept/technology provides significant improvement over these other solutions; and
- A reasonable and effective strategy for transitioning the proposed technology to commercial deployment.

(2) *Overall Scientific and Technical Merit* (35%) - This criterion involves consideration of the following:

Whether the proposed approach is unique and innovative;

- Feasibility of the proposed work based upon preliminary data or other background information and sound scientific and engineering practices and principles; and
- A sound technical approach to accomplish the proposed R&D objectives.

(3) *Qualifications, Experience, and Capabilities of the Proposed Applicant Team* (30%) - This criterion involves consideration of the following**:**

The PI (Applicant Team Leader) and Applicant Team have the skill and expertise needed to successfully execute the project plan, evidenced by prior experience that demonstrates an ability to perform R&D of similar risk and complexity.

The above criteria will be weighted as follows:

Impact of the Proposed Technology	35%
Overall Scientific and Technical Merit	35%
Qualifications, Experience, and Capabilities of the Proposed Applicant Team	30%

B. REVIEW AND SELECTION PROCESS

1. PROGRAM POLICY FACTORS

In addition to the above criteria, ARPA-E may consider the following program policy factors in determining which Full Applications to select for award negotiations:

I. **ARPA-E Portfolio Balance**. Project balances ARPA-E portfolio in one or more of the following areas:
   a. Diversity of technical personnel in the proposed Applicant Team;
   b. Technological diversity;
   c. Organizational diversity;
   d. Geographic diversity;
   e. Technical or commercialization risk; or
   f. Stage of technology development.

II. **Relevance to ARPA-E Mission Advancement.** Project contributes to one or more of ARPA-E's key statutory goals:
   a. Reduction of US dependence on foreign energy sources;
   b. Reduction of energy-related emissions;
   c. Increase in U.S. energy efficiency;
   d. Enhancement of U.S. economic and energy security; or
   e. Promotion of U.S. advanced energy technologies competitiveness.

III. **Synergy of Public and Private Efforts**.
   a. Avoids duplication and overlap with other publicly or privately funded projects; or
   b. Increases unique research collaborations.

IV. **Low likelihood of other sources of funding.** High technical and/or financial uncertainty that results in the non-availability of other public, private or internal funding or resources to support the project.

2. ARPA-E Reviewers

By submitting an application to ARPA-E, Applicants consent to ARPA-E's use of Federal employees, contractors, and experts from educational institutions, nonprofits, industry, and governmental and intergovernmental entities as reviewers. ARPA-E selects reviewers based on their knowledge and understanding of the relevant field and application, their experience and skills, and their ability to provide constructive feedback on applications.

ARPA-E requires all reviewers to complete a Conflict-of-Interest Certification and Nondisclosure Agreement through which they disclose their knowledge of any actual or apparent conflicts and agree to safeguard confidential information contained in Full Applications. In addition, ARPA-E trains its reviewers in proper evaluation techniques and procedures.

Applicants are not permitted to nominate reviewers for their applications. Applicants may contact the Contracting Officer by email (ARPA-E-CO@hq.doe.gov) if they have knowledge of a potential conflict of interest or a reasonable belief that a potential conflict exists.

Reviewers for this FOA will not be eligible to participate in Challenge 1 of the GO Competition.

3. ARPA-E Support Contractor

ARPA-E utilizes contractors to assist with the evaluation of applications and project management. To avoid actual and apparent conflicts of interest, ARPA-E prohibits its support contractors from submitting or participating in the preparation of applications to ARPA-E.

By submitting an application to ARPA-E, Applicants represent that they are not performing support contractor services for ARPA-E in any capacity and did not obtain the assistance of ARPA-E's support contractor to prepare the application. ARPA-E will not consider any applications that are submitted by or prepared with the assistance of its support contractors.

C. Anticipated Announcement and Award Dates

ARPA-E expects to announce selections for negotiations in approximately October 2018 and to award funding agreements in approximately December 2018.

VI. AWARD ADMINISTRATION INFORMATION

A. AWARD NOTICES

1. REJECTED SUBMISSIONS

Noncompliant and nonresponsive Full Applications are rejected by the Contracting Officer and are not merit reviewed or considered for award. The Contracting Officer sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. The notification letter states the basis upon which the Full Application was rejected.

2. FULL APPLICATION NOTIFICATIONS

ARPA-E promptly notifies Applicants of its determination. ARPA-E sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. The notification letter may inform the Applicant that its Full Application was selected for award negotiations, or not selected. Alternatively, ARPA-E may notify one or more Applicants that a final selection determination on particular Full Applications will be made at a later date, subject to the availability of funds and other factors.

a. SUCCESSFUL APPLICANTS

ARPA-E has discretion to select all or part of a proposed project for negotiation of an award. A notification letter selecting a Full Application for award negotiations does not authorize the Applicant to commence performance of the project. **ARPA-E selects Full Applications for award negotiations, not for award.** Applicants do not receive an award until award negotiations are complete and the Contracting Officer executes the funding agreement. ARPA-E may terminate award negotiations at any time for any reason.

Please refer to Section IV.E.2 of the FOA for guidance on pre-award costs. Please also refer to the "Applicants' Guide to ARPA-E Award Negotiations" (https://arpa-e.energy.gov/?q=arpa-e-site-page/pre-award-guidance) for guidance on the award negotiation process.

b. POSTPONED SELECTION DETERMINATIONS

A notification letter postponing a final selection determination until a later date does not authorize the Applicant to commence performance of the project. ARPA-E may ultimately determine to select or not select the Full Application for award negotiations.

c. UNSUCCESSFUL APPLICANTS

By not selecting a Full Application, ARPA-E intends to convey its lack of programmatic interest in the proposed project. Such assessments do not necessarily reflect judgments on the merits of the proposed project. ARPA-E hopes that unsuccessful Applicants will submit innovative ideas and concepts for future FOAs.

Applicants that are not selected for award negotiations under this FOA may still participate as an Open Entrant in the GO Competition Challenge 1. See the GO Competition website Rules Document (https://gocompetition.energy.gov/competition-rules) regarding competing in Challenge 1 and eligibility for an award.

B. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS

The following administrative and national policy requirements apply to Prime Recipients. The Prime Recipient is the responsible authority regarding the settlement and satisfaction of all contractual and administrative issues, including but not limited to disputes and claims arising out of any agreement between the Prime Recipient and a FFRDC contractor. Prime Recipients are required to flow down these requirements to their Subrecipients through subawards or related agreements.

1. DUNS NUMBER AND SAM, FSRS, AND FEDCONNECT REGISTRATIONS

Prime Recipients and Subrecipients are required to obtain a Dun and Bradstreet Data Universal Numbering System (DUNS) number at http://fedgov.dnb.com/webform and to register with the System for Award Management (SAM) at https://www.sam.gov/portal/SAM/.
Prime Recipients and Subrecipients should commence this process as soon as possible in order to expedite the execution of a funding agreement. Obtaining a DUNS number and registering with SAM could take several weeks.

Prime Recipients are also required to register with the Federal Funding Accountability and Transparency Act Subaward Reporting System (FSRS) at https://www.fsrs.gov/.[14] Prime Recipients are required to report to FSRS the names and total compensation of each of the Prime Recipient's five most highly compensated executives and the names and total compensation of each Subrecipient's five most highly compensated executives. Please refer to https://www.fsrs.gov/ for guidance on reporting requirements.

ARPA-E may not execute a funding agreement with the Prime Recipient until it has obtained a DUNS number and completed its SAM and FSRS registrations. In addition, the Prime Recipient may not execute subawards with Subrecipients until they obtain a DUNS number and complete

[15] The Federal Funding Accountability and Transparency Act, P.L. 109-282, 31 U.S.C. 6101 note.

their SAM registration. Prime Recipients and Subrecipients are required to keep their SAM and FSRS data current throughout the duration of the project.

Finally, Prime Recipients are required to register with FedConnect in order to receive notification that their funding agreement has been executed by the Contracting Officer and to obtain a copy of the executed funding agreement. Please refer to https://www.fedconnect.net/FedConnect/Default.htm for registration instructions.

2. NATIONAL POLICY ASSURANCES

Awardee Teams, including Prime Recipients and Subrecipients, are required to comply with the National Policy Assurances attached to their funding agreement in accordance with 2 C.F.R. 200.300. Please refer to Attachment 6 of ARPA-E's Model Grant (https://arpa-e.energy.gov/?q=site-page/funding-agreements) for information on the National Policy Assurances.

3. INTELLECTUAL PROPERTYAND DATA MANAGEMENT PLANS

ARPA-E requires every Awardee Team to negotiate and establish an Intellectual Property Management Plan for the management and disposition of intellectual property arising from the project. The Prime Recipient must submit a completed and signed Intellectual Property Management plan to ARPA-E within six weeks of the effective date of the ARPA-E funding agreement. All Intellectual Property Management Plans are subject to the terms and conditions of the ARPA-E funding agreement and its intellectual property provisions, and applicable Federal laws, regulations, and policies, all of which take precedence over the terms of Intellectual Property Management Plans.

ARPA-E has developed a template for Intellectual Property Management Plans (https://arpa-e.energy.gov/?q=site-page/project-management-reporting-requirements) so as to facilitate and expedite negotiations between Awardee Team members. ARPA-E does not mandate the use of this template. ARPA-E and DOE do not make any warranty (express or implied) or assume any liability or responsibility for the accuracy, completeness, or usefulness of the template. ARPA-E and DOE strongly encourage Awardee Teams to consult independent legal counsel before using the template.

Awardees are also required, post-award, to submit a Data Management Plan (DMP) that addresses how data generated in the course of the work performed under an ARPA-E award will be preserved and, as appropriate, shared publicly. The Prime Recipient must submit a completed and signed DMP - as part of the Team's Intellectual Property Management Plan - to ARPA-E within six weeks of the effective date of the ARPA-E funding agreement. The DMP must meet the minimum requirements set forth in ARPA-E's "Applicant Guide to Award

Negotiations" available at the following website: https://arpa-e.energy.gov/?q=arpa-e-site-page/pre-award-guidance."

4. Corporate Felony Convictions and Federal Tax Liability

In submitting an application in response to this FOA, the Applicant represents that:

- It is not a corporation that has been convicted of a felony criminal violation under any Federal law within the preceding 24 months; and

- It is not a corporation that has any unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or have lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability.

For purposes of these representations the following definitions apply: A Corporation includes any entity that has filed articles of incorporation in any of the 50 states, the District of Columbia, or the various territories of the United States [but not foreign corporations]. It includes both for-profit and non-profit organizations.

5. Applicant Risk Analysis

If selected for award negotiations, ARPA-E may evaluate the risks posed by the Applicant using the criteria set forth at 2 CFR §200.205(c), subparagraphs (1) through (4). ARPA-E may require special award terms and conditions depending upon results of the risk analysis.

6. Recipient Integrity and Performance Matters

Prior to making a Federal award with a total amount of Federal share greater than the simplified acquisition threshold (presently $250,000), ARPA-E is required to review and consider any information about Applicants that is contained in the Office of Management and Budget's designated integrity and performance system accessible through SAM (currently the Federal Awardee Performance and Integrity Information System or FAPIIS) (41 U.S.C. § 2313 and 2 C.F.R. 200.205).

Applicants may review information in FAPIIS and comment on any information about itself that a Federal awarding agency previously entered into FAPIIS.

ARPA-E will consider any written comments provided by Applicants during award negotiations, in addition to the other information in FAPIIS, in making a judgment about an Applicant's integrity, business ethics, and record of performance under Federal awards when reviewing potential risk posed by Applicants as described in 2 C.F.R. §200.205.

7. NONDISCLOSURE AND CONFIDENTIALITY AGREEMENTS REPRESENTATIONS

In submitting an application in response to this FOA the Applicant represents that:

(1) **It does not and will not** require its employees or contractors to sign internal nondisclosure or confidentiality agreements or statements prohibiting or otherwise restricting its employees or contractors from lawfully reporting waste, fraud, or abuse to a designated investigative or law enforcement representative of a Federal department or agency authorized to receive such information.

(2) **It does not and will not** use any Federal funds to implement or enforce any nondisclosure and/or confidentiality policy, form, or agreement it uses unless it contains the following provisions:

a. *"These provisions are consistent with and do not supersede, conflict with, or otherwise alter the employee obligations, rights, or liabilities created by existing statute or Executive order relating to (1) classified information, (2) communications to Congress, (3) the reporting to an Inspector General of a violation of any law, rule, or regulation, or mismanagement, a gross waste of funds, an abuse of authority, or a substantial and specific danger to public health or safety, or (4) any other whistleblower protection. The definitions, requirements, obligations, rights, sanctions, and liabilities created by controlling Executive orders and statutory provisions are incorporated into this agreement and are controlling."*

b. The limitation above shall not contravene requirements applicable to Standard Form 312, Form 4414, or any other form issued by a Federal department or agency governing the nondisclosure of classified information.

c. Notwithstanding provision listed in paragraph (a), a nondisclosure confidentiality policy form or agreement that is to be executed by a person connected with the conduct of an intelligence or intelligence-related activity, other than an employee or officer of the United States Government, may contain provisions appropriate to the particular activity for which such document is to be used. Such form or agreement shall, at a minimum, require that the person will not disclose any classified information received in the course of such activity unless specifically authorized to do so by the United States Government. Such nondisclosure or confidentiality forms shall also make it clear that they do not bar disclosure to congress, or to an authorized official of an executive agency or the Department of Justice, that are essential to reporting a substantial violation of law.

C. Reporting

Recipients are required to submit periodic, detailed reports on technical, financial, and other aspects of the project, as described in Attachment 4 to ARPA-E's Model Grant (https://arpa-e.energy.gov/?q=site-page/funding-agreements).

VII. Agency Contacts

A. Communications with ARPA-E

Upon the issuance of a FOA, only the Contracting Officer may communicate with Applicants. ARPA-E personnel and our support contractors are prohibited from communicating (in writing or otherwise) with Applicants regarding the FOA. This "quiet period" remains in effect until ARPA-E's public announcement of its project selections.

During the "quiet period," Applicants are required to submit all questions regarding this FOA to ARPA-E-CO@hq.doe.gov. Questions and Answers (Q&As) about ARPA-E and the FOA are available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, please send an email with the FOA name and number in the subject line to ARPA-E-CO@hq.doe.gov. Due to the volume of questions received, ARPA-E will only answer pertinent questions that have not yet been answered and posted at the above link.

- ARPA-E will post responses on a weekly basis to any questions that are received that have not already been addressed at the link above. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.

- ARPA-E will cease to accept questions approximately 10 business days in advance of each submission deadline. Responses to questions received before the cutoff will be posted approximately one business day in advance of the submission deadline. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.

- Responses are published in a document specific to this FOA under "CURRENT FUNDING OPPORTUNITIES – FAQS" on ARPA-E's website (http://arpa-e.energy.gov/faq).

Applicants may submit questions regarding ARPA-E eXCHANGE, ARPA-E's online application portal, to ExchangeHelp@hq.doe.gov. ARPA-E will promptly respond to emails that raise legitimate, technical issues with ARPA-E eXCHANGE. ARPA-E will refer any questions regarding the FOA to ARPA-E-CO@hq.doe.gov.

ARPA-E will not accept or respond to communications received by other means (e.g., fax, telephone, mail, hand delivery). Emails sent to other email addresses will be disregarded.

During the "quiet period," only the Contracting Officer may authorize communications between ARPA-E personnel and Applicants. The Contracting Officer may communicate with Applicants as necessary and appropriate. As described in Section IV.A of the FOA, the Contracting Officer may arrange pre-selection meetings and/or site visits during the "quiet period."

B. DEBRIEFINGS

ARPA-E does not offer or provide debriefings.

VIII. OTHER INFORMATION

A. TITLE TO SUBJECT INVENTIONS

Ownership of subject inventions is governed pursuant to the authorities listed below. Typically, either by operation of law or under the authority of a patent waiver, Prime Recipients and Subrecipients may elect to retain title to their subject inventions under ARPA-E funding agreements.

- Domestic Small Businesses, Educational Institutions, and Nonprofits: Under the Bayh-Dole Act (35 U.S.C. § 200 et seq.), domestic small businesses, educational institutions, and nonprofits may elect to retain title to their subject inventions. If they elect to retain title, they must file a patent application in a timely fashion.

- All other parties: The Federal Non-Nuclear Energy Research and Development Act of 1974, 42. U.S.C. 5908, provides that the Government obtains title to new inventions unless a waiver is granted (*see below)*.

- Class Waiver: Under 42 U.S.C. § 5908, title to subject inventions vests in the U.S. Government and large businesses and foreign entities do not have the automatic right to elect to retain title to subject inventions. However, ARPA-E typically issues "class patent waivers" under which large businesses and foreign entities that meet certain stated requirements, such as cost sharing of at least 20%, may elect to retain title to their subject inventions. If a large business or foreign entity elects to retain title to its subject invention, it must file a patent application in a timely fashion. If the class waiver does not apply, a party may request a waiver in accordance with 10 C.F.R. §784.

- GOGOs are subject to the requirements of 37 C.F.R. Part 501.

B. GOVERNMENT RIGHTS IN SUBJECT INVENTIONS

Where Prime Recipients and Subrecipients retain title to subject inventions, the U.S. Government retains certain rights.

1. GOVERNMENT USE LICENSE

The U.S. Government retains a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States any subject invention throughout the world. This license extends to contractors doing work on behalf of the Government.

2. MARCH-IN RIGHTS

The U.S. Government retains march-in rights with respect to all subject inventions. Through "march-in rights," the Government may require a Prime Recipient or Subrecipient who has elected to retain title to a subject invention (or their assignees or exclusive licensees), to grant a license for use of the invention. In addition, the Government may grant licenses for use of the subject invention when Prime Recipients, Subrecipients, or their assignees and exclusive licensees refuse to do so.

The U.S. Government may exercise its march-in rights if it determines that such action is necessary under any of the four following conditions:

- The owner or licensee has not taken or is not expected to take effective steps to achieve practical application of the invention within a reasonable time;

- The owner or licensee has not taken action to alleviate health or safety needs in a reasonably satisfactory manner; or

- The owner has not met public use requirements specified by Federal statutes in a reasonably satisfactory manner.

C. RIGHTS IN TECHNICAL DATA

Data rights differ based on whether data is first produced under an award or instead was developed at private expense outside the award.

- Background or "Limited Rights Data": The U.S. Government will not normally require delivery of technical data developed solely at private expense prior to issuance of an award, except as necessary to monitor technical progress and evaluate the potential of proposed technologies to reach specific technical and cost metrics.

- Generated Data: The U.S. Government normally retains very broad rights in technical data produced under Government financial assistance awards, including the right to distribute to the public. However, pursuant to special statutory authority, certain categories of data generated under ARPA-E awards may be protected from public disclosure for up to five years in accordance with provisions that will be set forth in the award. Authorization of further enhanced rights to promote dissemination of software may also be available. In addition, invention disclosures may be protected from public disclosure for a reasonable time in order to allow for filing a patent application.

D. PROTECTED PERSONALLY IDENTIFIABLE INFORMATION

Applicants may not include any Protected Personally Identifiable Information (Protected PII) in their submissions to ARPA-E. Protected PII is defined as data that, if compromised, could cause harm to an individual such as identity theft. Listed below are examples of Protected PII that Applicants must not include in their submissions.

- Social Security Numbers in any form;
- Place of Birth associated with an individual;
- Date of Birth associated with an individual;
- Mother's maiden name associated with an individual;
- Biometric record associated with an individual;
- Fingerprint;
- Iris scan;
- DNA;
- Medical history information associated with an individual;
- Medical conditions, including history of disease;
- Metric information, e.g. weight, height, blood pressure;
- Criminal history associated with an individual;
- Ratings;
- Disciplinary actions;
- Performance elements and standards (or work expectations) are PII when they are so intertwined with performance appraisals that their disclosure would reveal an individual's performance appraisal;
- Financial information associated with an individual;
- Credit card numbers;
- Bank account numbers; and
- Security clearance history or related information (not including actual clearances held).

E. FOAS AND FOA MODIFICATIONS

FOAs are posted on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/), Grants.gov (http://www.grants.gov/), and FedConnect (https://www.fedconnect.net/FedConnect/). Any modifications to the FOA are also posted to these websites. You can receive an e-mail when a modification is posted by registering with FedConnect as an interested party for this FOA. It is recommended that you register as soon as possible after release of the FOA to ensure that you receive timely notice of any modifications or other announcements. More information is available at https://www.fedconnect.net.

F. Obligation of Public Funds

The Contracting Officer is the only individual who can make awards on behalf of ARPA-E or obligate ARPA-E to the expenditure of public funds. A commitment or obligation by any individual other than the Contracting Officer, either explicit or implied, is invalid.

ARPA-E awards may not be transferred, assigned, or assumed without the prior written consent of a Contracting Officer.

G. Requirement for Full And Complete Disclosure

Applicants are required to make a full and complete disclosure of the information requested in the Business Assurances & Disclosures Form. Disclosure of the requested information is mandatory. Any failure to make a full and complete disclosure of the requested information may result in:

- The rejection of a Full Application;
- The termination of award negotiations;
- The modification, suspension, and/or termination of a funding agreement;
- The initiation of debarment proceedings, debarment, and/or a declaration of ineligibility for receipt of Federal contracts, subcontracts, and financial assistance and benefits; and
- Civil and/or criminal penalties.

H. Retention of Submissions

ARPA-E expects to retain copies of all Full Applications and other submissions. No submissions will be returned. By applying to ARPA-E for funding, Applicants consent to ARPA-E's retention of their submissions.

I. Marking of Confidential Information

ARPA-E will use data and other information contained in Full Applications strictly for evaluation purposes.

Full Applications and other submissions containing confidential, proprietary, or privileged information must be marked as described below. Failure to comply with these marking requirements may result in the disclosure of the unmarked information under the Freedom of

Information Act or otherwise. The U.S. Government is not liable for the disclosure or use of unmarked information, and may use or disclose such information for any purpose.

The cover sheet of the Full Application or other submission must be marked as follows and identify the specific pages containing confidential, proprietary, or privileged information:

> Notice of Restriction on Disclosure and Use of Data:
>
> Pages [___] of this document may contain confidential, proprietary, or privileged information that is exempt from public disclosure. Such information shall be used or disclosed only for evaluation purposes or in accordance with a financial assistance or loan agreement between the submitter and the Government. The Government may use or disclose any information that is not appropriately marked or otherwise restricted, regardless of source.

The header and footer of every page that contains confidential, proprietary, or privileged information must be marked as follows: "Contains Confidential, Proprietary, or Privileged Information Exempt from Public Disclosure." In addition, every line and paragraph containing proprietary, privileged, or trade secret information must be clearly marked with double brackets .

IX. GLOSSARY

Applicant: The entity that submits the application to ARPA-E. In the case of a Applicant Team, the Applicant is the lead organization listed on the application.

Application: The entire submission received by ARPA-E, including the Full Application, and Reply to Reviewer Comments.

ARPA-E: is the Advanced Research Projects Agency – Energy, an agency within the U.S. Department of Energy.

Challenge: A focused effort on a particular grid software problem.

GO Competition: ARPA-E's broader pursuit to innovate and modernize grid software systems.

Deliverable: A deliverable is the quantifiable goods or services that will be provided upon the successful completion of a project task or sub-task.

DOE: U.S. Department of Energy.

DOE/NNSA: U.S. Department of Energy/National Nuclear Security Administration

FFRDCs: Federally Funded Research and Development Centers.

FOA: Funding Opportunity Announcement.

GOCOs: U.S. Government Owned, Contractor Operated laboratories.

GOGOs: U.S. Government Owned, Government Operated laboratories.

Milestone: A milestone is the tangible, observable measurement that will be provided upon the successful completion of a project task or sub-task.

Prime Recipient: The signatory to the funding agreement with ARPA-E.

PI: Principal Investigator.

Applicant Team: An **Applicant** Team consists of the Prime Recipient, Subrecipients, and others performing inventive supportive work that is part of an ARPA-E project.

Standalone Applicant: An Applicant that applies for funding on its own, not as part of an Applicant Team.

Subject Invention: Any invention conceived or first actually reduced to practice under an ARPA-E funding agreement.

Task: A task is an operation or segment of the work plan that requires both effort and resources. Each task (or sub-task) is connected to the overall objective of the project, via the achievement of a milestone or a deliverable.

Total Project Cost: The sum of the Prime Recipient share and the Federal Government share of total allowable costs. The Federal Government share generally includes costs incurred by GOGOs, FFRDCs, and GOCOs.

APPENDIX A1: ARPA-E GO COMPETITION CHALLENGE 1: OVERVIEW AND PROGRAM INFORMATION

1. BACKGROUND

Since the dawn of the age of electrification, electric power system engineers and operators have been required to manage the real-time matching of instantaneous electricity generation and demand – especially in the absence of cost effective and ubiquitous electricity storage. Achieving a continuous match between supply and demand requires utilities, grid operators, and other stakeholders to use a variety of sophisticated energy management systems (EMS), market management systems (MMS), dynamic security assessment (DSA) tools, and other decision support tools. These systems employ optimization models and algorithms, control systems, and/or simulations that cover a wide spectrum of applications that vary in mathematical program type, structure, complexity, and timescale. Decision stages include long-term analysis (e.g., investment planning), midterm analysis (maintenance scheduling, outage coordination, and various reliability and stability assessments), operational planning stages (e.g., day-ahead security constrained unit commitment), and real-time operations and situational awareness.

A number of emerging trends will substantially alter the planning, operations, control, and reliability standards of electric grids over the next several decades. These trends include the high penetration of stochastic resources for which forecasts are uncertain (such as wind and solar), changing electricity demand patterns, and the improving cost effectiveness of distributed energy resources (including storage). Operational protocols and software support systems have long since treated bulk power plants as the primary source of operational flexibility necessary to ensure a reliable and efficient operation. Instead, there is a paradigm shift where flexible bulk resources are being replaced by bulk stochastic resources (wind and solar) with limited flexibility while distributed energy resources are emerging to provide flexibility. Innovative grid software is necessary to plan under and adapt to growing penetrations of stochastic resources for which availability is both more variable than conventional generators and highly probabilistic, at best. The expected growth in system complexity will require the development of substantially improved grid software to assist grid operators to ensure not just a continuous supply of reliable electricity but to achieve a sustainable, clean, and affordable electric power economy, a necessity for any advanced society.

Many new optimization methods have been proposed in the research community in recent years and many claims have been made regarding the possible practical benefits that these new algorithms might offer utilities and power grid operations in general. However, today, it is extremely difficult to compare relative strengths and weaknesses of different proposed approaches. The vast majority of reports only test new algorithms on either relatively small-scale power network models, which often must be heavily modified to satisfy the modeling requirements specific to individual algorithms, or on proprietary datasets that inherently cannot be released for wide-spread performance testing. Computational experiments are also typically conducted on a variety of systems, ranging from commodity laptops to large-scale clusters with many thousands of nodes. Even small changes in how specific constraints are modeled or which constraints are considered can have significant implications for algorithm selection and performance as well as solution quality. Electrification was chosen as the greatest achievement of the 20th century by the National Academy of Engineering based on technical achievements for one of the most complex engineered systems that then forms a backbone for any modern society. A new paradigm for the testing and evaluation of emerging software solutions is needed to accelerate the adoption of transformational technologies for this critical and complex engineered system.

In response, ARPA-E has announced the GO Competition. The goal of the GO Competition is to accelerate the development of transformational and disruptive methods for solving the most pressing power system problems. The GO Competition will be staged as a series of challenges in power systems to address emerging needs and new technologies on the grid. Challenge 1 focused on security-constrained optimal power flow (SCOPF). With this competition, ARPA-E aims to provide fair and transparent comparisons of industrially-relevant algorithm performance on high-fidelity, open-access, large-scale power system models and a platform for the identification of transformational and disruptive methods for solving power system optimization problems.

2. Opportunities in Grid Software and Optimization Methods

The optimal power flow (OPF) problem is the central optimization challenge underlying a large suite of grid planning and operational tools. Simply stated, the OPF problem is that of finding the optimal dispatch and control settings for power generation, flexible customer demand, energy storage, and grid control equipment that maximize one or more grid objectives, while the SCOPF problem additionally considers security constraints.[15,16,17] In order to be deployable, the recommended settings must satisfy all physical constraints of electric power infrastructure and applicable operating standards. These standards include, but are not limited to, minimum and maximum voltages at each node (bus), minimum and maximum power generation from each generator, thermal transmission constraints, proxy stability constraints, and constraints to

[15] J. Carpentier, "Contribution to the economic dispatch problem," *Bulletin de la Société Française des Électriciens*, ser. 8, vol. 3, pp. 431-447, 1962.
[16] H. W. Dommel and W. F. Tinney, "Optimal power flow solutions," *IEEE Transactions on Power Apparatus and Systems*, vol. 87, no. 10, pp 1866-1876, October 1968.
[17] There are a variety of specific applications for OPF. The specific objective function and the constraints can vary widely. In many applications, where demand is considered fixed, the objective is considered to be minimization of total generation cost.

ensure the reliability of the system while responding to unexpected events and outages (i.e., contingencies). For a more complete history and formal problem formulation, we refer the reader to a paper authored by the Federal Energy Regulatory Commission (FERC).[18]

Note that approaches that solve an OPF problem without regard for security constraints are of limited use to industry and are not of interest to ARPA-E.

Improved SCOPF algorithms can yield significant benefits. Recent studies have suggested that enhanced SCOPF algorithms can offer as much as 5-10% reductions in total U.S. electricity cost by improving our management of grid resources in order to reduce network and operational limitations, corresponding to a savings of $6-$19B.[19,20] In addition to monetary savings, improved optimization algorithms are likely to help ensure reliable system operation as power flows become more dynamic.[21] To fully realize the potential benefits of renewable generation as well as recently developed electric transmission power flow controllers, distribution automation technologies, distributed energy resources, and energy storage, software support tools will require more complex (and fundamentally nonlinear) grid operation optimization and dispatch algorithms. Furthermore, as the number of controllable resources connected to both transmission and distribution systems grow substantially, along with the reliance on stochastic resources, it is important to examine approaches that will handle the increasing complexities driven by the size, non-convexities, and uncertainties associated with power grid management problems. Advances in optimization methods and decision support tools are paramount to overcome these complicating factors and to reduce the reliance on operator intuition and the reliance on conventional technologies. In this context, the importance of new SCOPF methods was recently recognized by the National Academies.[22]

The core SCOPF solution methods predominantly used in industry today were designed in an era when computers were far less capable and more costly than they are currently and formal general purpose optimization solvers were in their infancy. Grid operators, power system software vendors, and the research community were required to make a range of simplifying assumptions, most commonly a set of linearizing assumptions that ignore voltage and reactive power, referred to as a direct current optimal power flow (DCOPF). While many proprietary variations on SCOPF models, approximations, and solution techniques have been developed

[18] M. B. Cain, R. P. O'Neill, and A. Castillo, "History of optimal power flow and formulations," Federal Energy Regulatory Commission, Washington, DC, August 2013, http://www.ferc.gov/industries/electric/indus-act/market-planning/opf-papers/acopf-1-history-formulation-testing.pdf.

[19] M. Ilic, "Modeling of hardware and systems related transmission limits: the use of AC OPF for relaxing transmission limits to enhance reliability and efficiency," *Presentation at FERC Staff Technical Conference on Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software*, Washington, DC, June 2013, http://www.ferc.gov/CalendarFiles/20140411131533-T2-B%20-%20Ilic.pdf.

[20] M. B. Cain, R. P. O'Neill, and A. Castillo, "History of optimal power flow and formulations," Federal Energy Regulatory Commission, Washington, DC, August 2013, http://www.ferc.gov/industries/electric/indus-act/market-planning/opf-papers/acopf-1-history-formulation-testing.pdf.

[21] GE Energy, "Western wind and solar integration study," National Renewable Energy Laboratory, Technical Report No. NREL/SR-550-47434, May 2010, http://www.nrel.gov/docs/fy10osti/47434.pdf.

[22] National Academies of Sciences, Engineering, and Medicine. Analytic Research Foundations for the Next-Generation Electric Grid. Washington, DC: The National Academies Press, 2016. doi: 10.17226/21919.

over the past decades by industry vendors, the most commonly used optimization software packages, including production cost models, security-constrained unit commitment (SCUC), and security-constrained economic dispatch (SCED) tools rely on linear OPF assumptions such as the assumptions found in a classical DCOPF problem. Despite improvements in formulations, approximation techniques, and solvers, there are no tools currently in widespread use in industry that use the full AC power flow equations (without linearizing assumptions) and simultaneously co-optimize both real and reactive power generation.

The SCOPF tools in use today often result in conservative solutions that must be iteratively checked for physical feasibility before implementation. The development and demonstration at scale of SCOPF solution methods providing physically feasible solutions and capable of optimizing both real and reactive power generation and demand within the time limits required for practical application remains an open, unsolved problem. Achieving these capabilities are expected to become critical in the future as electric power systems evolve to include more widely distributed and stochastic resources, especially as SCOPF becomes more important in the context of electric distribution systems.

There are reasons to believe that recent advances could enable significantly improved SCOPF approaches. Dramatic improvements in computational power and advancements in optimization solvers in recent years have prompted research on new approaches to grid operations and new approaches to solve SCOPF and other grid problems.[23] Since the turn of the millennium, the performance of the most powerful supercomputers has increased by almost four orders of magnitude while the cost per computational step has dropped by approximately the same factor.[24,25] Improvements in optimization and search methods have evolved similarly, especially those related to mixed integer programming (MIP) and heuristic-based optimization methods. The relative speed of commercial general-purpose solvers, such as CPLEX and GUROBI, has also increased by over three orders of magnitude on fixed hardware.[26,27] Cloud computing, which can be used to leverage many of these gains, has also started to gain more widespread interest within the power system engineering community.[28]

In tandem, many new approaches to solve SCOPF problems have been proposed in the literature in recent years; it appears increasingly likely that scalable and more accurate approaches to solve the SCOPF problem may be within reach. For example, recent research has moved from linear approximations to convex relaxations for the classical SCOPF problem. Fast and accurate convex relaxations have been formulated where the global optimum can be found

[23] P. Panciatici et al., "Advanced optimization methods for power systems," *Proceedings of the 18th Power System Computation Conference*, Wroclaw, Poland, August 2014, pp. 1-18, doi: 10.1109/PSCC.2014.7038504.
[24] http://www.top500.org/
[25] https://intelligence.org/2014/05/12/exponential-and-non-exponential/
[26] http://www.gurobi.com
[27] T. Koch et al., "MIPLIB 2010," *Mathematical Programming Computation*, vol. 3, no. 2, pp. 103-163, June 2011, doi: 10.1007/s12532-011-0025-9
[28] J. Goldis et al., "Use of cloud computing in power market simulations," Presentation at FERC Staff Technical Conference on Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software, Washington, DC, June 2014.

efficiently using quadratic convex, semi-definite, and second order cone programming approaches.[29,30,31,32,33] Furthermore, it has been shown that there are situations when a convex relaxation of the OPF problem can still find the global optimum to the original non-convex mathematical program.[34,35] Distributed and parallelizable SCOPF algorithms have also been proposed, for example, using the alternating direction method of multipliers (ADMM), suggesting that SCOPF solution algorithms can be designed that leverage more advanced computational hardware.[36,37,38] These same algorithms could enable the real-time coordination and optimization of large numbers of distributed energy resources. Advances in general optimization methods, as well as those from other fields, may lend insights to solve SCOPF problems. For example, work in machine learning has focused on efficiently finding solutions to non-convex optimization problems. Methodologies developed, such as new variations on stochastic gradient descent, may help efficiently find solutions to the non-convex ACOPF problem.[39,40,41] SCOPF problems that solve both pre-contingency and post-contingency states may also benefit from recent research into decomposition methods or stochastic optimization algorithms that seek to exploit a similar two-stage problem structure.[42,43] Finally, many unique methodologies using techniques such as genetic algorithms, neural networks, fuzzy algorithms,

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[29] S. Low, "Convex relaxation of optimal power flow, Part I: Formulations and equivalence," *IEEE Transactions on Control of Network Systems*, vol. 1, no. 1, pp. 15-27, March 2014, doi: 10.1109/TCNS.2014.2309732.

[30] S. Low, "Convex relaxation of optimal power flow, Part II: Exactness," *IEEE Transactions on Control of Network Systems*, vol. 1, no. 2, pp. 177-189, May 2014, doi: 10.1109/TCNS.2014.2323634.

[31] R. Madani, S. Sojoudi, and J. Lavaei, "Convex relaxation for optimal power flow problem: Mesh networks," *IEEE Transactions on Power Systems*, vol. 30, no. 1, pp. 199-211, May 2014, doi: 10.1109/TPWRS.2014.2322051.

[32] D. Molzahn et al., "Implementation of a large-scale optimal power flow solver based on semidefinite programming," *IEEE Transactions on Power Systems*, vol. 28, no. 4, pp. 3987-3998, April 2013, doi: 10.1109/TPWRS.2013.2258044.

[33] C. Coffrin, H. Hijazi, and P. Van Hentenryck, "Strengthening the SDP relaxation of AC power flows with convex envelopes, bound tightening, and valid inequalities," *IEEE Transactions on Power Systems*, vol. 32, no. 5, pp. 3549-3558, September 2017, doi: 10,1109/TPWRS.2016.2634586.

[34] J. Lavaei and S. Low, "Zero duality gap in optimal power flow problem," *IEEE Transactions on Power Systems*, vol. 27, no. 1, pp. 92-107, August 2011, doi: 10.1109/TPWRS.2011.2160974.

[35] L. Gan et al., "Exact convex relaxation of optimal power flow in radial networks," *IEEE Transactions on Automatic Control*, vol. 60, no. 1, pp. 72-87, June 2014, doi: 10.1109/TAC.2014.2332712.

[36] A. Sun, D.T. Phan, and S. Ghosh, "Fully decentralized AC optimal power flow algorithms," *IEEE Power and Energy Society General Meeting*, Vancouver, BC, Canada, July 2013, doi: 10.1109/PESMG.2013.6672864.

[37] S. Magnússon, P. Weeraddana, and C. Fischione, "A distributed approach for the optimal power flow problem based on ADMM and sequential convex approximations," *arXiv preprint* arXiv: 1401.4621, January 2014.

[38] B. H. Kim and R. Baldick, "A comparison of distributed optimal power flow algorithms." *IEEE Transactions on Power Systems*, vol. 15, no. 2, pp. 599-604, May 2000, doi: 10.1109/59.867147.

[39] P. Jain and P. Kar, "Non-convex optimization for machine learning," *Foundations and Trends in Machine Learning,* vol. 10, no. 3-4, pp. 142-336, December 2017, doi: 10.1561/2200000058.

[40] R. Ge et al., "Escaping from saddle points – online stochastic gradient for tensor decomposition," *JMLR: Workshop and Conference Proceedings*, vol. 40, pp. 1-46, 2015.

[41] Z. Allen-Zhu and E. Hazan, "Variance reduction for faster non-convex optimization," *Proceedings of the 33rd International Conference on Machine Learning*, vol. 48, pp. 699-707, June 2016.

[42] F. Capitanescu et al., "State-of-the-art, challenges, and future trends in security constrained optimal power flow," *Electric Power Systems Research*, vol. 81, pp. 1731-1741, 2011.

[43] F. Capitanescu, "Critical review of recent advances and further developments needed in AC optimal power flow," *Electric Power Systems Research*, vol. 136, pp. 57-68, 2016.

and holomorphic embedding have also emerged claiming, in many cases, to revolutionize solution methods for SCOPF. [44,45]

The end-result has been numerous research projects and papers on improved grid optimization strategies and many new algorithms that may be able to significantly impact grid operation and control. However, most of these advances have not yet moved past the early research stage. One critical roadblock to their adoption has been the lack of publicly available, large-scale, and high-fidelity power system network models on which to test new solution methods and/or perform valid comparisons. Most recent grid operation optimization advances still have not been validated on realistic, large-scale test models and their operational limits also remain largely unexplored.[46]

3. THE GO COMPETITION CHALLENGE 1: SCOPF

ARPA-E intends to launch the GO Competition series in the Fall of 2018, and Challenge 1 will focus on SCOPF.[47] It is important to note that a necessary first step for any meaningful SCOPF competition must be the development of many small, medium, and large-scale, realistic power system network descriptions and operating scenarios defining a variety of challenging operating conditions (reflecting both the existing electric power system and that in the future). The primary objective of the ARPA-E GRID DATA (Generating Realistic Information for the Development of Distribution And Transmission Algorithms) program[48], launched in early 2016, is the development of these datasets, an example of which is depicted in Figure 1. The GRID DATA program will provide many of the power system datasets to be used in the upcoming GO Competition.

[44] X. F. Wang, Y. Song, and M. Irving, *Modern power systems analysis*, New York, NY: Springer Science & Business Media, 2008.
[45] A. Trias, "The holomorphic embedding load flow method," *IEEE Power and Energy Society General Meeting*, San Diego, CA, July 2012, doi: 10.1109/PESGM.2012.6344759.
[46] ARPA-E "Generating Realistic Information for Development of Distribution and Transmission Algorithms (GRID DATA)," Funding Opportunity Announcement Number DE-FOA-0001357, June 2015, https://arpa-e.energy.gov/?q=pdfs/grid-data-de-foa-0001357.
[47] See https://gocompetition.energy.gov/.
[48] http://arpa-e.energy.gov/?q=arpa-e-programs/grid-data.

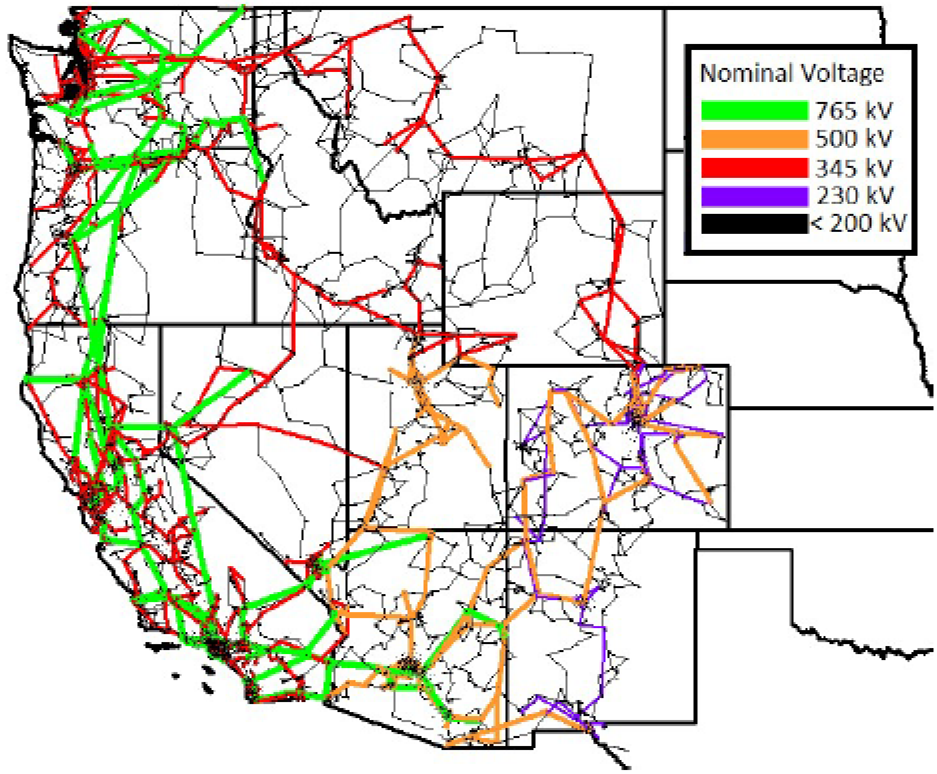

Figure 1. 10,000 Node Synthetic Network Model on the Footprint of the Western United States.[49]

For Challenge 1 of the competition, datasets containing power system network models with corresponding scenarios and contingencies will be released at the start of the GO Competition Challenge 1, which will allow Entrants to test their SCOPF algorithms prior to submitting the algorithms for Trial Event 1, Trial Event 2, and the Final Event (official scoring for the determination of prizes). Trial Event 1, Trial Event 2, and the Final Event are described in more details regarding algorithm submission, scoring, and the release of datasets used for these events in Section 3.B and Section 3.C within this appendix, Appendix A1. Additionally, a specific problem formulation will be provided (a focused version of which can be found in Appendix A2 of this FOA) along with a descriptive scoring criteria (https://gocompetition.energy.gov/challenges/challenge-1/scoring) on the GO Competition website. The provided problem formulation and modeling approach described will be used for solution evaluation. Entrants will be permitted and encouraged to use any approximation or reformulation of the official problem formulations, alternative modeling conventions, and/or solution methods within their own software; however, the resulting solution must comply with the official formulation. Indeed, we anticipate Entrants will use a variety of model formulations (to enhance computational efficiency and/or promote finding a solution) and will use a mix of formal optimization solution methods and unique heuristics. Entrants are welcome to interpret the fundamental nature of the SCOPF problem and its application as they see fit; for example,

[49] A. B. Birchfield, T. Xu, K. M. Gegner, K. S. Shetye, and T. J. Overbye, "Grid structural characteristics as validation criteria for synthetic networks," *IEEE Transactions on Power Systems*, vol. 32, no. 4, pp. 3258-3265, July 2017.

Entrants may choose to mathematically decompose the problem in various ways. Regardless of the method and model formulation used within each Entrant's software, all Entrants will be required to provide their solution (variable setpoints) in a form that is compatible with the selected, published competition problem formulation. It is important to note that the formulation employs an Alternating Current (AC) formulation, though Entrants do not have to employ full AC optimization methods within their competition software.

Entrants will interact with the competition via a hosted computational platform with a web front-end portal (https://gocompetition.energy.gov/). Algorithms will be submitted for formal evaluation (and scoring) by the official competition platform throughout all challenges of the competition. Submissions can either be source code that must be compiled, linked, and executed, interpreted and executed, or a binary execution file. Each submission will be run on the controlled, secure evaluation platform with no external communications. The competition evaluation platform will provide access to several popular licensed solvers (please refer to the competition website for an up-to-date list of supported solvers). Solutions requiring licensed software not provided by the platform will have to be self-contained.

Public leaderboards will be maintained during the competition on the web portal as described below. Entrants can participate as individuals or in teams. Please see the Rules Document posted on the GO Competition website (https://gocompetition.energy.gov/competition-rules) for more information.

A. Challenge 1: Fall 2018-Fall 2019

Challenge 1 will focus on the SCOPF problem and utilize multiple unique datasets. Each dataset will consist of a collection of power system network models of different sizes with associated operating scenarios (for more details on the distinction between power system network models and operating scenarios, see details on scoring: https://gocompetition.energy.gov/challenges/challenge-1/scoring.

Challenge 1 will focus on solely transmission networks while future challenges may involve optimizing settings for power flow over both transmission and distribution systems or more complicated grid software variants (see below). It is expected that many datasets will be open source and include models generated by the ARPA-E GRID DATA program. Datasets will be released on the GO Competition website throughout the twelve month period of Challenge 1. System models and datasets made publicly available in the GO Competition will not contain or constitute Critical Energy Infrastructure Information (CEII).[50] Any datasets or system models used in the GO Competition that do contain CEII will be maintained according to all applicable requirements and established industry best practices.

[50] See 18 C.F.R. § 388.113(c)(1). The term "CEII" means "specific engineering, vulnerability, or detailed design information about proposed or existing critical infrastructure that: (i) relates details about the production, generation, transportation, transmission, or distribution of energy; (ii) could be useful to a person in planning an attack on critical infrastructure; (iii) is exempt from mandatory disclosure under the Freedom of Information Act,5 U.S.C. Part 552; and (iv) Does not simply give the general location of the critical infrastructure."

The datasets used for the Final Event will not be released in advance of the judging process but all open access datasets will be released after all judging is completed and the winners are determined. Note that the Final Event may include datasets that are not from the ARPA-E GRID DATA program and that will not publicly released after the judging is finalized for Challenge 1; these datasets may be proprietary industry cases that cannot be released. Proprietary datasets will be stored at a secure location by the GO Competition Administrator;[51] algorithm performance against actual datasets will contextualize and validate the GO Competition Challenge 1 results for the research and industry communities.

The "Challenge 1 Original Dataset (C1OD)" will be released at the start of Challenge 1 in order to allow Entrants to start developing solution methods and test their approach on the GO Competition platform. Entrants will be able to download the datasets in order to test algorithms within their own development environment. Entrants can also submit software to be scored against the C1OD dataset using the official competition platform at any time. Scores will be generated after each algorithm submission and will be displayed on a set of competition leaderboards, accessible via the competition website. Entrants may choose to remain anonymous on the leaderboards or may choose to display their Entrant name associated with their scores. However, Entrants that choose to remain anonymous are ineligible for awards under this competition. For more information on scoring, see https://gocompetition.energy.gov/challenges/challenge-1/scoring.

B. Trials (Spring 2019, Summer 2019)

Two trial events will be conducted before the Final Event to allow the Entrants to view their performance on datasets that have not been publicly released. Approximately six and nine months into Challenge 1, the two dry-run "trial" rounds for the SCOPF competition will be held utilizing new power system datasets, Challenge 1 Trial Dataset 1 (C1TD1) and Challenge 1 Trial Dataset 2 (C1TD2). The models in these datasets will be similar in scope to those in C1OD, but they will not be publically released until after the conclusion of each trial event. Entrants are expected to update their submitted approach throughout Challenge 1 and, in particular, before Trial Event 1 and Trial Event 2. The datasets used throughout the GO Competition Challenge 1 are likely to increase in size and complexity. Larger network models combined with a significant selection of contingencies are to be expected for the two trial runs.

Prior to each trial event, there will be a deadline for Entrants to submit their SCOPF software approach before the judging is conducted; these deadlines will be posted at the launch (start) of the GO Competition Challenge 1 in the fall of 2018. Immediately following the deadline, the software from all Entrants will be run and scored against C1TD1 and C1TD2, respectively. After each trial event, scores for each Entrant submission will be displayed on a set of competition

[51] The Pacific Northwest National Laboratory (PNNL) is acting as the GO Competition Administrator, the host team of the competition. Additionally, there are sub-contractors that are supporting PNNL and ARPA-E in regards to the GO Competition Challenge 1 (Arizona State University, National Renewable Energy Laboratory, Texas A&M University, the University of Wisconsin-Madison).

leader boards. The objective of the trial events is to give Entrants experience in using the portal for the competition and to troubleshoot any potential algorithm submission and evaluation problems in the context of a specified deadline, as will be required in the Challenge 1 Final Event.

The datasets used for scoring for each trial event (C1TD1 and C1TD2) will be released to the public as soon as scoring and evaluation of all algorithms has been completed. C1TD1 and C1TD2 will remain available for scoring runs using the official competition platform throughout the remainder of the competition and Entrants will have the ability to submit new software/algorithms (to be tested against C1TD1 or C1TD2) at any time. A continuously updated leaderboard will be maintained.

C. Challenge 1 Final Event (Fall 2019)

At the conclusion of Challenge 1, the Final Event will occur, which will include the official scoring that will determine the final placement of the Entrants for purposes of making awards. GO Competition formulations, scoring, and rules will be similar to those in each trial event, with a new Challenge 1 Final Dataset (C1FD) used for evaluation and scoring. Like the two trial events, the deadline for Entrants to submit their SCOPF solution software will be announced at the start of the GO Competition Challenge 1. Immediately following the deadline, the software from all Entrants will be run and scored against C1FD. Scores for each Entrant submission will be displayed on a series of competition leaderboards.

Competition winners will be determined based on the final scores (see https://gocompetition.energy.gov/challenges/challenge-1/scoring) subject to the winning criteria specified in the GO Competition Rules Document (see https://gocompetition.energy.gov/competition-rules). The datasets that are used for the Final Event, C1FD, will be made publicly available only after the scoring is finalized and the winners are announced.

D. Challenge 2 and Beyond (Details TBD): Fall 2019-Fall 2020

Future competitions, beginning with Challenge 2, are expected to build on the models used in Challenge 1 and may include complicating factors such as solving larger network models, optimizing power flows over both transmission and distribution systems, stochastic optimization, leveraging power flow control devices, increased model detail (node/breaker, substation/protection models, etc.) and/or including unit commitment. Challenge 2 will likely also focus on OPF, with some of the above complicating factors, and will likely disburse fewer awards in increased amounts for the winning Entrants. ARPA-E reserves the right to revise plans for Challenge 2 or future challenges to follow. ARPA-E may also release additional FOAs to provide additional Proposal Entrants funding for future challenges.

E. Competition Timeline: Challenge 1

The proposed Challenge 1 competition timeline is illustrated below.

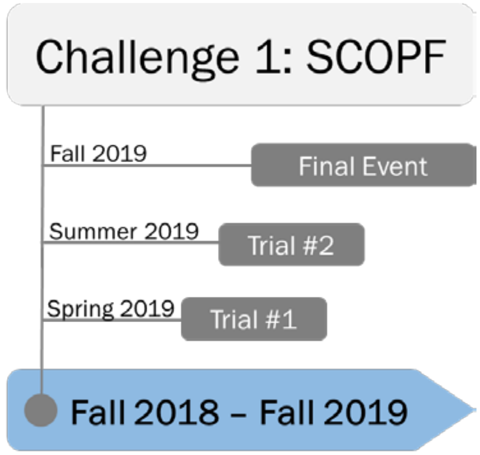

Figure 2. Challenge 1 Competition Timeline.

ARPA-E intends for the competition platform to be capable of hosting a wide range of power system algorithm research competitions. Once the processes are established and the award competition model has been validated, private sector entities or other government agencies will have the option of commissioning and sponsoring additional award competitions, contributing to a new era of innovation in electric power systems research.

4. GO Competition Details and Website

The definitive (and evolving) source of all details related to the GO Competition including details regarding participation eligibility requirements, the standardized evaluation platform, Challenge 1 modeling details, and scoring metrics can be found at the GO Competition website, https://gocompetition.energy.gov/. The official SCOPF formulation can be found on the GO Competition website along with other information pertaining to the hardware platform and available software. While frequent changes are not expected, ARPA-E reserves the right to change any of these details. Potential Entrants should visit the GO Competition website for updates and should provide contact information during the registration process so that they can be notified when there are changes.

5. Open Entrants and Proposal Entrants

ARPA-E is providing two parallel paths for participating in the GO Competition Challenge 1: a *Proposal Entrant Path* and an *Open Entrant Path*. Each Entrant's score and ranking throughout the competition will be based on the same technical evaluation criteria and scoring mechanisms for all Entrants, irrespective of path.

Proposal Entrants for Challenge 1 will be competitively selected on the basis of proposals submitted to this FOA. It is anticipated that up to 20 teams selected under this FOA would receive grants of up to $250,000.

Teams who do not apply as Proposal Entrants, or are not selected under this FOA, may participate as Open Entrants. Open Entrants registration materials will be made available on the competition website prior to Challenge 1 and a deadline for registration will be established. Neither ARPA-E nor the GO Competition Administrator will gain rights to software developed by Open Entrants as a result of participation in the competition and Open Entrants will not be required to publicly disclose their solution methods.

Competition and award money eligibility requirements are detailed in the GO Competition Rules Document in https://gocompetition.energy.gov/competition-rules, for both Proposal Entrants and Open Entrants. ARPA-E reserves the right to disqualify an Entrant at any time when their actions are deemed to violate the rules of the competition, including but not limited to, the violation of relevant laws or regulations in the course of participation in the competition. ARPA-E does not authorize or consent to competition participants infringing on any U.S. patent or copyright while participating in the competition. No illegal activities may be undertaken for the purpose of participation in the competition.

6. Scoring and Award (Prize Money and Grants)

Following the Challenge 1 GO Competition Final Event, ARPA-E will determine the top ten winning teams in four separate scoring divisions, see Figure 3 and Figure 4. Scoring divisions are defined based on scoring method and time in which algorithms must return as solution. Details on scoring divisions and scoring methodology can be found in (https://gocompetition.energy.gov/challenges/challenge-1/scoring). Subject to the availability of appropriated funds, the planned award amount is $100,000 for each Eligible Entrant (see the Rules document describing eligibility for receiving awards through the GO Competition Challenge 1 from the GO Competition website: https://gocompetition.energy.gov/competition-rules) placing in the top ten of each division; Eligible Entrants can receive one award in each division (the total award amount is additive). Awards given to Open Entrants will be prize money. Awards given to Proposal Entrants will be additional grant funding from ARPA-E to further develop their algorithm. Receipt of this funding: (i) requires submission of a brief application, and (ii) is subject to ARPA-E's standard grant terms and conditions (including cost sharing requirements, if applicable). ARPA-E reserves the right to discontinue negotiations without the award of a grant in the event the parties can not agree on the terms of the prospective grant. Please see the eligibility requirements as outlined in (https://gocompetition.energy.gov/competition-rules). Open Entrants will not be restricted in how they utilize the funds. However, Open Entrants will be encouraged to use those funds to participate in Challenge 2.

Figure 3. Awards for Eligible Open Entrants and Proposal Entrants.

Figure 4. Scoring Divisions; Prizes are Only for Award-Eligible Entrants.

Challenge 2 will likely also focus on a more complicated version of the OPF problem and will likely disburse fewer prizes in increased amounts for Entrants. Challenge 2 awards are expected to total approximately $2M for the top three winners (in aggregate), though ARPA-E reserves the right to revise Challenge 2.

ARPA-E expects to actively publicize the results of the GO Competition. In particular, award winners from Challenge 1 (prize money recipients and grant recipients) should expect the active publicizing of their results by ARPA-E and winners will be encouraged to participate in related events such as an industry outreach event and the annual ARPA-E Energy Innovation Summit.

APPENDIX A2: ARPA-E GO COMPETITION CHALLENGE 1: *FOCUSED* FORMULATION AND MODELING APPROACH

1. INTRODUCTION

The following mathematical formulation and modeling approach is proposed to give applicants to ARPA-E DE-FOA-0001952 an idea of the structure of the Challenge 1 problem. **Please note that this document presents a focused version of the actual Challenge 1 formulation, which can be found on the GO Competition website (https://gocompetition.energy.gov/). Please refer to this formulation frequently, as it is subject to change**. The official Challenge 1 problem formulation and modeling approach (on the website) will be used for solution evaluation; Entrants will be permitted and encouraged to use any alternative problem formulation and modeling convention within their own software (such as convex relaxations, decoupled power flow formulations, current-voltage formulations, etc.) to align with their chosen solution method. However, the judging of all submitted approaches will conform to the Challenge 1 formulation on the website.

2. NOMENCLATURE AND MODELING ASSUMPTIONS

A. Sets and Indices:

A power grid is made up by a set of nodes (also called buses) and branches (composed of lines, transformers, and other transmission elements) connecting the nodes together in a network. Various resources (generators, loads, etc.) are connected to the nodes. All indices and only indices are shown as subscripts throughout this document. Network components are indexed as:

$e \in E$ — Set of branches (edges). $E(i,j)$ denotes the subset of branches connecting node i directly to node j. Each branch (edge) appears once in the set E with a given 'from/source node' referenced as i and a given 'to/receiving node' referenced as j to form $E(i,j)$. $E(i)^+$ denotes the subset of branches that have node i defined as the 'from/source node'. $E(i)^-$ denotes the subset of branches that have node i defined as the 'to/receiving node'. The addition of subscript k denotes the corresponding subset of branches that are available in contingency k.

$g \in G$ — Set of generators; $G(i)$ denotes the subset of generators connected to node i. The addition of subscript k denotes the corresponding subset of generators that are available in contingency k.

$i \in N, j \in N$ Set of nodes; $N(i)$ denotes the subset of nodes directly connected to node i. $N(g)$ denotes the node that is directly connected to generator g.

$k \in K$ Set (or subset) of *N*-1 contingencies, i.e., the unexpected loss of a single generator or a bulk transmission asset (line or transformer). The lack of a subscript k denotes the base-case (pre-contingency) operational state.

B. Parameters:

i. Transmission Modeling:

For the presented *focused* security-constrained optimal power flow (SCOPF) formulation in this FOA, the only transmission elements being modeled are transmission lines. The line characteristics are captured by the conductance, g_e, and the susceptance, b_e, based on the diagram given below.

b_e Susceptance of branch e (edge) in the network.

g_e Conductance of branch e (edge) in the network.

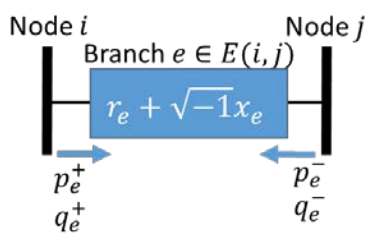

Figure 1. Branch Diagram.

$r_e + \sqrt{-1}x_e = z_e$ where r_e is the resistance, x_e is the reactance, and z_e is the impedance. Then, $y_e = \frac{1}{z_e} = g_e + \sqrt{-1}b_e = \frac{1}{(r_e+\sqrt{-1}x_e)} = \frac{(r_e-\sqrt{-1}x_e)}{(r_e-\sqrt{-1}x_e)}\frac{1}{(r_e+\sqrt{-1}x_e)} = \frac{r_e}{(r_e)^2+(x_e)^2} + \sqrt{-1}\frac{-x_e}{(r_e)^2+(x_e)^2}$ to form: $g_e = \frac{r_e}{(r_e)^2+(x_e)^2}$ and $b_e = \frac{-x_e}{(r_e)^2+(x_e)^2}$.

In general, a traditional power system has many controllable transmission elements (some of which are switchable) including, but not limited to, capacitor banks, shunt elements, tap changing transformers, transmission lines, flexible AC transmission system (FACTS) devices, and phase shifters. For the formulation presented in this FOA, g_e and b_e are fixed representations (parameters) of the equivalent conductance and susceptance between two directly connected nodes in the network, which represents a fixed operational state of the transmission elements directly joining these nodes. Explicit mathematical formulations of all transmission devices are needed to properly capture all operational states of the system and may cause additional complexities for the optimization problem (e.g., nonlinearities and/or discrete states). **In the focused version of the problem formulation presented in this FOA**, such advanced features of optimal power flow are not explicitly stated. Each Entrant's approach must be able to provide the adequate setpoint for any decision variable defined within the official formulation posted on the GO Competition website, **which is more complex than the focused formulation posted in this FOA**. Those applying to the FOA should keep in mind that their proposed algorithmic approach needs to reflect the official formulation for the GO Competition (https://gocompetition.energy.gov/challenges/challenge-1/formulation) and not only the focused formulation presented in this appendix for this FOA.

ii. Real Power and Reactive Power Demand:

The following parameters provide the fixed inputs for the net real power and reactive power consumption throughout the network. Note that many nodes will have a value of zero (no load) at the node.

D_i^P	Real power demand at node i (MW).
D_i^Q	Reactive power demand at node i (MVAr).

iii. Resource Limits:

The following parameters provide the limits for generators, node voltages, and transmission element flow limits.

P_g^{max}, P_g^{min}	Maximum and minimum real power generation limit at generator g (MW).
Q_g^{max},Q_g^{min}	Maximum and minimum reactive power generation limit at generator g (MVAr).
S_e^{max}	Mega-Volt Ampere (MVA)[52] capacity (rate A) of branch $e \in E$; these limits are imposed for the base-case pre-contingency state.
$S_e^{max_C}$	Mega-Volt Ampere (MVA) emergency capacity (rate C) of branch $e \in E$; these limits are imposed across all contingency states.
V_i^{max}, V_i^{min}	Maximum and minimum voltage magnitude limits at node i (kV).

iv. Participation Factors:

The following parameter models a generator's response to a contingency and do not apply to the base case. After a contingency occurs, the network automatically readjusts by modulating the amount of power being generated according to each generator's participation factor α_g. In this generalized formulation, the participation factor does not include a contingency subscript;

[52] Example units are provided throughout this focused formulation to aid the applicants for this FOA. Precise unit definitions to be used in input and output data files will be provided on the competition website. For instance, line limits may be represented as a current limit instead of the MVA power flow limit presented above.

in the actual formulation these may also be functions of each contingency or region (balancing area). This factor is predetermined (and will be provided to competitors) and the adjustments are assumed to occur instantaneously.

α_g Participation factor for generator g (unitless).

v. Penalty Prices for Slack Variables:

These slack variable penalties will be provided as part of each power system network model and based on the prices used in real industry markets.[53] Penalty prices are the same for the base-case (pre-contingency) and the post-contingency states.

λ^S Penalty prices for the slack variables corresponding to the branch flow complex power (S) overload ($/MVAh).

λ^P, λ^Q Penalty prices for the slack variables corresponding to the nodal imbalance for real and reactive power ($/MWh, $/MVArh).

C. Variables:

i. Generator Real and Reactive Power Setpoints:

Each generator has a variable representing its setpoint for its real power and reactive power output (dispatch).

p_g Real power dispatched at generator g in the base-case (MW).

$p_{g,k}$ Real power dispatched at generator g available in contingency k (MW).

q_g Reactive power dispatched at generator g in the base-case (MVAr).

$q_{g,k}$ Reactive power dispatched at generator g available in contingency k (MVAr).

ii. Transmission Power Flows:

Power flows throughout the network are determined by the structure of the network, the power injections and withdrawals at nodes, and the setpoints for grid control equipment. Each transmission asset has a real power and reactive power flow variable corresponding to each end of the branch. See Figure 1 for a pictorial representation. These power flows are represented as:

p_e^+ Real power flow on branch e: $\forall i \in N, \forall e \in E(i)^+$, measured from node i (withdrawal) in the base-case (MW) where node i is listed as the 'from/source node' for branch e.

[53] California ISO. Market Parameter Settings for MRTU Market Launch. February 2009.

p_e^- Real power flow on branch e: $\forall i \in N, \forall e \in E(i)^-$, measured from node i (withdrawal) in the base-case (MW) where node i is listed as the 'to/receiving node' for branch e.

$p_{e,k}^+$ Real power flow on branch e: $\forall i \in N, \forall k \in K, \forall e \in E(i)_k^+$, measured from node i (withdrawal) in the base-case (MW) where node i is listed as the 'from/source node' for branch e available in contingency k.

$p_{e,k}^-$ Real power flow on branch e: $\forall i \in N, \forall k \in K, \forall e \in E(i)_k^-$, measured from node i (withdrawal) in the base-case (MW) where node i is listed as the 'to/receiving node' for branch e available in contingency k.

q_e^+ Reactive power flow on branch e: $\forall i \in N, \forall e \in E(i)^+$, measured from node i (withdrawal) in the base-case (MVAr) where node i is listed as the 'from/source node' for branch e.

q_e^- Reactive power flow on branch e: $\forall i \in N, \forall e \in E(i)^-$, measured from node i (withdrawal) in the base-case (MVAr) where node i is listed as the 'to/receiving node' for branch e.

$q_{e,k}^+$ Reactive power flow on branch e: $\forall i \in N, \forall k \in K, \forall e \in E(i)_k^+$, measured from node i (withdrawal) in the base-case (MVAr) where node i is listed as the 'from/source node' for branch e available in contingency k.

$q_{e,k}^-$ Reactive power flow on branch e: $\forall i \in N, \forall k \in K, \forall e \in E(i)_k^-$, measured from node i (withdrawal) in the base-case (MVAr) where node i is listed as the 'to/receiving node' for branch e available in contingency k.

iii. Nodal Variables:

Each node (bus) has a voltage magnitude and phase angle:

v_i Voltage magnitude at node i in the base-case (kV).

$v_{i,k}$ Voltage magnitude at node i available in contingency k (kV).

θ_i Voltage phase angle at node i in the base-case (radians).

$\theta_{i,k}$ Voltage phase angle at node i available in contingency k (radians).

iv. Slack Variables:

Slack variables are included to account for line flow limits (MVA) and nodal imbalances (real power and reactive power) at each node (bus):

s_e	Slack variables accounting for the complex power flow excess across each transmission (line) branch e (MVA).
s_i^{+P}, s_i^{-P}	Slack variables accounting for real power excess, $+$, or shortfall, $-$, at each node (MW).
s_i^{+Q}, s_i^{-Q}	Slack variables accounting for reactive power excess, $+$, or shortfall, $-$, at each node (MVAr).
$s_{e,k}$	Slack variables accounting for the complex power flow excess across each transmission (line) branch e (MVA).
$s_{i,k}^{+P}, s_{i,k}^{-P}$	Slack variables accounting for real power excess, $+$, or shortfall, $-$, at each node in contingency k (MW).
$s_{i,k}^{+Q}, s_{i,k}^{-Q}$	Slack variables accounting for reactive power excess, $+$, or shortfall, $-$, at each node in contingency k (MVAr).

v. *Post-Contingency Response:*

A free variable is used to capture the net change in supply dictated by the subset of generators that are following the participation factor response:

Δ_k	Net real power (MW) supply change for contingency k based on generators following participation factors. The change in injection for a generator responding to the contingency is determined by $\alpha_g \Delta_k$.

3. MODEL FORMULATION

A. Functions:

There are several parameters that may affect the cost of production (e.g. fuel costs, heat rates, environmental regulations, etc.). In this generalized formulation, all of these factors (when relevant) are assumed to be included within the function definition. Generator operational cost functions, $C_g(p_g)$, will be piecewise linear with monotonically non-decreasing marginal costs.

$C_g(p_g)$	Cost of producing power at generator g (\$/h).

B. Objective Function:

The objective function of the SCOPF problem is to minimize the system-wide total cost of electricity production, while also accounting for penalties on nodal imbalances, by optimizing the generator setpoints.

$$\text{Min: } \sum_{g\in G} C_g(p_g) + \delta\left(\sum_{i\in N}\left(\lambda^P(s_i^{+P} + s_i^{-P}) + \lambda^Q(s_i^{+Q} + s_i^{-Q})\right) + \sum_{e\in E}\lambda^S s_e\right)$$
$$+(1-\delta)\sum_{k\in K}\frac{1}{|K|}\left(\sum_{i\in N}\left(\lambda^P\left(s_{i,k}^{+P} + s_{i,k}^{-P}\right) + \lambda^Q\left(s_{i,k}^{+Q} + s_{i,k}^{-Q}\right)\right) + \sum_{e\in E}\lambda^S s_{e,k}\right) \qquad (1)$$

The total system cost is broken into three terms. The first term represents the total generation cost, which is realized in both the base-case (pre-contingency) and post-contingency states. The second term then represents the node-balance relaxations and the branch flow relaxations that occur in the base-case (pre-contingency) times their respective penalty prices; this term is weighted by δ, which is the assigned probability that no contingency occurs. The third term then captures the sum of all costs during the post-contingency states. The costs for the post-contingency states include the node-balance relaxations and their corresponding penalties. The weight given for all combined contingency states is $1-\delta$. Each contingency is assumed equally probable, which results in the $\frac{1}{|K|}$ above. For all models, scenarios, and datasets for the competition the value of δ will be the same. See the official formulation on the website for the prescribed value.

C. Constraints: Base-Case (Pre-Contingency) State:

i. AC Line Flow Equations:

Constraints (2)-(5) represent the AC power flow equations for the branch assumptions listed in Section 2. For a given branch e, there are two flow equations representing the flow, p_e^+ and q_e^+, leaving its assigned 'from/source node' and the flow, p_e^- and q_e^-, leaving its 'to/sink node'. Note that all AC line flow equations are written with the assumption that the current is leaving (a withdrawal from) the identified node; this is applied regardless as to whether the node is listed as the 'from/source node' or the 'to/sink node' for the branch e. For each branch e, there are four equations: the real and reactive power flows at each end of the branch. **Again, please note that this is a generalized formulation for the purpose of introducing the SCOPF problem within ARPA-E FOA-0001952.** Refer back to Figure 1 for a two-node diagram for further clarification on p_e^+, p_e^-, q_e^+, and q_e^-.

$$p_e^+ = (v_i)^2 g_e - v_i v_j\left(g_e\cos(\theta_i-\theta_j) + b_e\sin(\theta_i-\theta_j)\right) \qquad \forall i\in N, j\in N, \forall e\in E(i,j) \qquad (2)$$
$$p_e^- = (v_j)^2 g_e - v_j v_i\left(g_e\cos(\theta_j-\theta_i) + b_e\sin(\theta_j-\theta_i)\right) \qquad \forall i\in N, j\in N, \forall e\in E(j,i) \qquad (3)$$
$$q_e^+ = -(v_i)^2 b_e + v_i v_j\left(b_e\cos(\theta_i-\theta_j) - g_e\sin(\theta_i-\theta_j)\right) \qquad \forall i\in N, j\in N, \forall e\in E(i,j) \qquad (4)$$
$$q_e^- = -(v_j)^2 b_e + v_j v_i\left(b_e\cos(\theta_j-\theta_i) - g_e\sin(\theta_j-\theta_i)\right) \qquad \forall i\in N, j\in N, \forall e\in E(j,i) \qquad (5)$$

ii. Node Balance Constraints and Slack Variables:

Constraints (6)-(7) represent the node balance equations. For each node i in the network, there is a real power (MW) and a reactive power (MVAr) node balance equation where the total injected supply (first summation) equals the withdrawals from the line flows (the next two summation terms) combined with the load (withdrawal); two slack variables are added to capture the possibility of an imbalance. Note that there are two summation terms for the line flow withdrawals. Each branch e has a defined 'from/source node' and a 'to/sink node' based on the input dataset. For each node balance equation, the flow leaving that node on branch e would be identified through either its 'from/source node' or by its 'to/sink node', which produces two summation terms. Constraint (8) specify that all slack variables are non-negative.

$$\sum_{g\in G(i)} p_g = \sum_{e\in E(i)^+} p_e^+ + \sum_{e\in E(i)^-} p_e^- + D_i^P + s_i^{+P} - s_i^{-P} \qquad \forall i \in N \qquad (6)$$
$$\sum_{g\in G(i)} q_g = \sum_{e\in E(i)^+} q_e^+ + \sum_{e\in E(i)^-} q_e^- + D_i^Q + s_i^{+Q} - s_i^{-Q} \qquad \forall i \in N \qquad (7)$$
$$s_e, s_i^{+P}, s_i^{-P}, s_i^{+Q}, s_i^{-Q} \geq 0 \qquad \forall i \in N \qquad (8)$$

iii. Resource Limits:

Constraints (9)-(10) capture the generator lower and upper bounds on real and reactive power production. Constraint (11) imposes the voltage magnitude limit for each node. Constraints (12)-(13) impose the branch flow limit for the flow at each end of the branch. The branch limits are written for the complex power flow (squared), not for the individual real or reactive power flows.

$$P_g^{min} \leq p_g \leq P_g^{max} \qquad \forall g \in G \qquad (9)$$
$$Q_g^{min} \leq q_g \leq Q_g^{max} \qquad \forall g \in G \qquad (10)$$
$$V_i^{min} \leq v_i \leq V_i^{max} \qquad \forall i \in N \qquad (11)$$
$$(p_e^+)^2 + (q_e^+)^2 \leq (S_e^{max} + s_e)^2 \qquad \forall e \in E \qquad (12)$$
$$(p_e^-)^2 + (q_e^-)^2 \leq (S_e^{max} + s_e)^2 \qquad \forall e \in E \qquad (13)$$

D. Constraints: Post-Contingency States:

In order to obtain a secure (reliable) power flow solution, it must be subject to additional contingency constraints for each contingency k. This section covers the operational limitations in the post-contingency states, the assumptions related to the transition from the pre-contingency state to a potential post-contingency state, and the preventive and correction actions deployed to achieve a feasible post-contingency solution.

i. Post-Contingency AC Line Flow Equations:

The power flow line constraints are relatively unchanged and they become (14)-(17), which have been updated based on the post-contingency variables and line availability for the post-contingency state. The power flow limits, (18)-(19), are updated to reflect the emergency rating for the transmission asset. The short-term emergency rate C will be used; note that some transmission assets may have an emergency rating that is the same as the normal rating (rate A).

$$p_{e,k}^{+} = \left(v_{i,k}\right)^2 g_e - v_{i,k} v_{j,k}\left(g_e \cos\left(\theta_{i,k} - \theta_{j,k}\right) + b_e \sin\left(\theta_{i,k} - \theta_{j,k}\right)\right) \quad \forall i \in N, j \in N, k \in K, \forall e \in E(i,j)_k \quad (14)$$

$$p_{e,k}^{-} = \left(v_{j,k}\right)^2 g_e - v_{i,k} v_{j,k}\left(g_e \cos\left(\theta_{j,k} - \theta_{i,k}\right) + b_e \sin\left(\theta_{j,k} - \theta_{i,k}\right)\right) \quad \forall i \in N, j \in N, k \in K, \forall e \in E(j,i)_k \quad (15)$$

$$q_{e,k}^{+} = -\left(v_{i,k}\right)^2 b_e + v_{i,k} v_{j,k}\left(b_e \cos\left(\theta_{i,k} - \theta_{j,k}\right) - g_e \sin\left(\theta_{i,k} - \theta_{j,k}\right)\right) \quad \forall i \in N, j \in N, k \in K, \forall e \in E(i,j)_k \quad (16)$$

$$q_{e,k}^{-} = -\left(v_{j,k}\right)^2 b_e + v_{j,k} v_{i,k}\left(b_e \cos\left(\theta_{j,k} - \theta_{i,k}\right) - g_e \sin\left(\theta_{j,k} - \theta_{i,k}\right)\right) \quad \forall i \in N, j \in N, k \in K, \forall e \in E(j,i)_k \quad (17)$$

$$\left(p_{e,k}^{+}\right)^2 + \left(q_{e,k}^{+}\right)^2 \le \left(S_e^{max_C} + s_{e,k}\right)^2 \quad \forall e \in E, k \in K \quad (18)$$

$$\left(p_{e,k}^{-}\right)^2 + \left(q_{e,k}^{-}\right)^2 \le \left(S_e^{max_C} + s_{e,k}\right)^2 \quad \forall e \in E, k \in K \quad (19)$$

ii. Post-Contingency Node Balance Constraints and Slack Variables:

For each contingency k, the node balance contingency constraint for real power and reactive power are shown by (20)-(21). Note that the sets referenced in the summation terms include an index for k; this is a subset of the original set and is meant to reference which generators or branches are available during this particular contingency k. For Challenge 1 of the GO Competition, Entrants should assume that all assets are available to respond except for the asset that is assumed to be forced out of service due to the contingency. Constraint (22) specifies that all post-contingency slack variables are non-negative.

$$\sum_{g \in G(i)_k}\left(p_{g,k}\right) = \sum_{e \in E(i)_k^{+}} p_{e,k}^{+} + \sum_{e \in E(i)_k^{-}} p_{e,k}^{-} + D_{i,k}^{P} + s_{i,k}^{+P} - s_{i,k}^{-P} \quad \forall i \in N, k \in K \quad (20)$$

$$\sum_{g \in G(i)_k}\left(q_{g,k}\right) = \sum_{e \in E(i)_k^{+}} q_{e,k}^{+} + \sum_{e \in E(i)_k^{-}} q_{e,k}^{-} + D_{i,k}^{Q} + s_{i,k}^{+Q} - s_{i,k}^{-Q} \quad \forall i \in N, k \in K \quad (21)$$

$$s_{e,k}, s_{i,k}^{+P}, s_{i,k}^{-P}, s_{i,k}^{+Q}, s_{i,k}^{-Q} \ge 0 \quad \forall i \in N, k \in K \quad (22)$$

iii. Post-Contingency Generator Real Power Response and Participation Factor Modeling:

After a contingency occurs, a generator g may respond by changing its real power injection; this new injection should still stay within the generator's limits, (23). The manner in which it is restricted beyond (23) is covered in the remaining part of this section; however, (23) must hold regardless.

$$P_g^{min} \le p_{g,k} \le P_g^{max} \quad \forall g \in G, k \in K \quad (23)$$

Each generator is also supposed to follow its predetermined participation factor α_g. If the generator's lower bound on production, P_g^{min}, and its upper bound on production, P_g^{max}, are ignored, the generator's post-contingency output would be $p_g + \alpha_g \Delta_k$. However, given that the participation factors are determined offline a-priori and the generator's dispatch setpoint is not known at that time, the generator may not be able to provide the desired change in generation; instead, the generator may hit its minimum or maximum capacity first. For instance, a generator may be expected to inject 10%, $\alpha_g = 0.1$, of the required change in supply, Δ_k; suppose that system-wide change in supply needs to be 200MW and suppose that the generator is within 10MW of its maximum capacity. In this situation, the generator will increase its output by 10MW, not the anticipated 20MW, and stop when it reaches its maximum capacity. The additional 10MW that the generator did not provide will need to be compensated by the rest of the generators that are responding.

Suppose there are three sets of generators: (i) those that respond and reach their minimum production and fail to provide precisely $\alpha_g \Delta_k$, (ii) those that respond and reach their maximum production and fail to provide precisely $\alpha_g \Delta_k$, and (iii) those that respond and provide exactly $\alpha_g \Delta_k$ while staying within their lower and upper bounds. As previously stated, Δ_k is a free variable that absorbs the amount of MWs needed in the system in response to the contingency k ***based on the response of the fleet of generators that are responding by following their participation factor.*** As a result, Δ_k should be interpreted to be that free variable that adjusts to the net change in supply that is needed from only the third group of generators, those that are exactly following the anticipated participation factor. This description is meant to reflect the actual reaction by generators without a centralized control signal. **Based on this description, there are then three cases that describes each generator's post-contingency response for its change in real power.** Each generator will fall into one of these three categories, described by (24)-(28); keep in mind that the generator must also satisfy (23) on top of the requirements specified by the three following cases. Each Entrant's approach must produce a solution that falls into one of these three categories. Note that α_g is assumed to be non-negative for each generator. Even when α_g is assumed to be non-negative, it is possible for a generator to reach its minimum capacity, though unlikely, as Δ_k can be negative (indicating an excess of net supply) for a generator contingency or a transmission contingency.

Case 1:

$$p_{g,k} = p_g + \alpha_g \Delta_k \qquad \forall g \in G, k \in K \qquad (24)$$

Or Case 2:

$$p_{g,k} = P_g^{max} \qquad \forall g \in G, k \in K \qquad (25)$$

and

$$p_g + \alpha_g \Delta_k \geq P_g^{max} \qquad \forall g \in G, k \in K \qquad (26)$$

Or Case 3:

$$p_{g,k} = P_g^{min} \qquad \forall g \in G, k \in K \qquad (27)$$

and

$$p_g + \alpha_g \Delta_k \leq P_g^{min} \qquad \forall g \in G, k \in K \qquad (28)$$

The above three cases can be translated into an equivalent mathematical formulation capturing the choice of the program to choose the state for each generator. There are many different ways to restructure the logic described above. For instance, a mixed integer program formulation can be used to model disjunctive constraints where binary variables are used to reflect the chosen case. Please see the official formulation on the GO Competition website for more information as to how the above cases can be translated into a mathematical programming problem.

Note that each Entrant has the choice as to how the team wishes to handle the requirements stated by (24)-(28). For instance, a team could simply ignore these complicating disjunctive cases and could instead allow slack variables, at the generators' nodes, to pick up the required change in injection if the generator were to violate either of its limits. A mathematical representation of that would be to simply always have Case 1 but to modify (24) with the inclusion of the slack variable corresponding to that generator's node, as shown by (24a). Note that ARPA-E is not proposing Entrants take this approach; this is given as an example as to how an Entrant can choose a variant to the proposed official formulation. Imposing (24a) would produce a feasible solution to the official formulation but it would likely produce a sub-optimal solution. It is then up to the Entrant to decide whether to solve the more complex case described by the official formulation or to simplify the formulation to produce faster but potentially still good solutions.

$$p_{g,k} = p_g + \alpha_g \Delta_k - s^{+P}_{i \in N(g),k} + s^{-P}_{i \in N(g),k} \qquad \forall g \in G, k \in K \qquad (24a)$$

iv. Post-Contingency Generator Reactive Power Response and Voltage Control:

In addition to automatic adjustments in real power output outlined in the prior section, each generator's control system will attempt to modulate reactive power output to maintain the base case voltage at its node. However, the generator must always stay within its reactive power limits, (29). Furthermore, the voltage of all nodes in the system should be kept within its limits, (30). Added complexities associated to a generator's reactive power response in a post-contingency state are included in the remainder of this section; keep in mind that no matter the added complexities, (29)-(30) must still hold.

$$Q_g^{min} \le q_{g,k} \le Q_g^{max} \qquad \forall g \in G, k \in K \qquad (29)$$
$$V_i^{min} \le v_{i,k} \le V_i^{max} \qquad \forall i \in N, k \in K \qquad (30)$$

Entrants must select pre-contingency system setpoints with sufficient reactive power capacity to ensure that the voltage at node i can be maintained within limits for all contingencies, (30). After a contingency occurs, the voltage magnitude $v_{i,k}$ at each generator node $i \in N(g)$ will preferentially equal the voltage determined in the base case v_i while maintaining the aggregate reactive power output at each generator node i if doing so can be achieved within the total reactive power limits of local generators: $\sum_{g \in G(i)_k} Q_g^{min} \le \sum_{g \in G(i)_k} q_{g,k} \le \sum_{g \in G(i)_k} Q_g^{min}$. If this is not possible, aggregate local reactive power will bind at the lower bound $\sum_{g \in G(i)_k} Q_g^{min}$ or the upper bound $\sum_{g \in G(i)_k} Q_g^{max}$, and node voltages will be adjusted.

Such a description of the system response is broken into three cases. The nodes that have resources controlling voltage, $\forall g \in G, i \in N(g)$ (known as PV nodes), will try to maintain their pre-contingency voltage level: Case 1, (31)-(32); note that (32) is just a subset of the stated requirement by (29), just associated to the particular node i that is described by (31). If those resources cannot maintain their pre-contingency voltage (cannot satisfy Case 1), they will fall into the case described by (33)-(34) or (35)-(36). This modeling is referred to as PV/PQ node switching; when a generator reaches its reactive power limit, it is no longer able to regulate its voltage at its node and it switches to a node classification where there is a fixed injection of reactive power as opposed to a node where the voltage is being regulated. Note that (32), (34), and (36) all simply refer to a different subset of the stated requirement by (29), just associated to the particular node i that is described by (31), (33), or (35) respectively. Note that (29) and (30) must hold for all of the three cases.

The following equations representing the three cases all fall under the sets: $\forall i \in \bigcup_g N(g), k \in K$. That is, these cases do not apply to nodes that are not associated with a generator that is locally controlling its voltage (a PV node).

Case 1:

$$v_{i,k} = v_i \qquad \forall i \in \bigcup_g N(g), k \in K \tag{31}$$

and

$$Q_g^{min} \le q_{g,k} \le Q_g^{max} \qquad \forall i \in \bigcup_g N(g), k \in K, \forall g \in G(i) \tag{32}$$

Or Case 2:

$$v_{i,k} \le v_i \qquad \forall i \in \bigcup_g N(g), k \in K \tag{33}$$

and

$$q_{g,k} = Q_g^{max} \qquad \forall i \in \bigcup_g N(g), k \in K, \forall g \in G(i) \tag{34}$$

Or Case 3:

$$v_i \le v_{i,k} \qquad \forall i \in \bigcup_g N(g), k \in K \tag{35}$$

and

$$q_{g,k} = Q_g^{min} \qquad \forall i \in \bigcup_g N(g), k \in K, \forall g \in G(i) \tag{36}$$

Competitors must give solutions whose post-contingency control variables satisfy one of these three conditions, (31)-(32) or (33)-(34) or (35)-(36), at each node: $\forall i \in \bigcup_g N(g)$ of the network where there is a generator that is providing reactive power support. The above three cases can be translated into an equivalent mathematical formulation capturing the choice of the program to choose the state for each generator. There are many different ways to restructure the logic described above. For instance, a mixed integer program formulation can be used to model disjunctive constraints where binary variables are used to reflect the chosen case. Please see the official formulation on the GO Competition website for more information as to how the above cases can be translated into a mathematical programming problem.